HOUSEHOLD PHYSICS

FIG. 45. — WATER WAVES.

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HOUSEHOLD PHYSICS

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PREFACE

During recent years there has been an increased call for Physics as part of a general education. At the same time there has been a decided dislike for the subject as it has been presented. To meet both of these conditions, this book has been prepared.

Much has been said about the value of mathematics and science as a means of mental discipline. The writer's belief is that it is the excessive attention paid to the mathematical side of Physics, together with the development of formulas, that has made the subject so difficult for the average student. There can be just as good mental training in developing the thought that enables a pupil to answer a set of questions selected from every-day experiences, as can be obtained from the ability to solve a mass of problems, many of which have no connection with the life of the pupil, and therefore mean little to him.

The object of Household Physics is to present those phases of Physics which enter into the daily household life, introducing each principle by means of some well-known application, then explaining the principle, and finally presenting other applications as a means of clinching the principle; first the known, followed by the unknown, and ended by the known.

At the end of each main group of principles appears a set of questions on that group. At the end of each chapter is a set of questions covering the different groups in the chapter. At the end of the book are questions covering the different chapters. There is thus opportunity for three reviews, each covering a larger field than the one preceding. Complete answers to the questions cannot often be found in the text.

A well-founded knowledge of the principles and applications, however, will enable the pupil to think out the answers.

There is enough material in the text to allow the teacher considerable latitude in the selection of work for a year's course, and the pupil at the end should be in a position to appreciate the many phenomena that take place about him, and should be able to answer most of the questions that deal with Physics in our daily life.

Non-technical words have been used as far as possible in the explanations of principles and applications. Wherever necessary, the applications as well as the principles are given careful explanation, and are not left to the student to work out. Terms and definitions are for the most part introduced when their application follows almost immediately.

As far as possible the text is limited to physical phenomena, those phases of household life that come more properly under the realm of chemistry being purposely omitted.

While the order of presentation of subjects is not the same as that followed in most text-books, the writer feels that Heat is closer to the student's life than is Mechanics, and therefore affords a better way of arousing the interest and desire for information. The chapter on Mechanics is, however, presented in such a form that those who desire can just as well start with this chapter, and take up Heat second.

The chapter on Plumbing may be studied or not, as may seem best. There are no new principles presented in this chapter. It simply deals with the mechanical principles discussed in the preceding chapters, showing how these principles are applied in household plumbing.

Boys and girls are interested in Physics if only it can be presented in such a way as to have a real meaning to them.

Throughout Household Physics the writer has tried to present the subject more for the sake of the pupil than for the subject alone, and trusts that those who read may be awakened to observe and appreciate the many wonderful phenomena that take place daily about them.

The writer wishes to extend his thanks for the use of illustrations as follows:

To the Illuminating Engineering Company of New York for Figures 49, 60, 94, and 106; to the Weston Electrical Instrument Company for Figures 237, 238, 239, 240; to the Norman W. Henley Publishing Company of New York for Figures 327, 329, 332, 333, 336, 349.

In conclusion the writer wishes to thank Mr. Thomas G. Rees, of the Mechanic Arts High School of Boston, for valued criticism of the manuscript.

BOSTON, June, 1914. A. M. B.

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CHAPTER I

INTRODUCTION

1. In our daily experiences we note the many changes that are going on about us. It is these that give variety to life, and the better we are able to appreciate them and understand their causes the greater becomes our enjoyment of life.

Some of these changes are brought about by human or animal effort; others through what are called natural causes. In all of the changes something is accomplished for better or for worse. It may be said that the object of all existence is the accomplishment of something, small or great. This accomplishment may be that of the mind or that of the body. In the subject of Physics with which this book deals, bodily or physical accomplishment only is to be considered. The appreciation of it can come only through one of the five senses which are our only means of communication with the world about us.

2. **Physical and Chemical Changes.** When we melt ice or boil water, magnetize a piece of iron, light an incandescent lamp with the electric current, produce music by playing on a piano, or move objects about, we are in no way changing the identity or composition of the object. If the cause is removed the object returns to its original condition. On the other hand, when wood or gas burn, when meat decays, when iron rusts, when plants grow, the substance is changing its composition. In the first of these processes we have examples of *physical changes,* and in the second, of *chemical changes*. The latter will enter very little into our study.

3. **Energy.** Whenever anything happens there is some driving force behind the action. This driving force is due to what

...led energy. Energy is encountered in various forms—...ergy, sound energy, light energy, and electrical, chemical, ...scular energy—all of which bring about changes.

Work. Whenever the above forms of energy manifest ...lves they are said to do *work*. Whenever work is done, ...position of some sort, known as *resistance*, is overcome, ...change in condition results. Very frequently this change of motion. Whenever motion results, or is interfered ... may know that two forces are opposing and that one ... than the other.

Measurement. All the changes that are going on about ... daily life may be looked upon from two points of view, ...tative and the *quantitative;* the first has to do with the ... things and the second with the amount. If we are ... cloth, we must first find the material of proper tex- ... color, and then tell how much of it we need. This ...tive side of things requires a system of measurement. ... of length, as in the case of cloth; of area, as of lino- ... volume, as of milk, wood, or gas; of weight, as of ... and meats; or even of time, when we employ labor. ... olden times trades were made by bartering, in which ...ent satisfactory to both parties was made on the spot, ... trade completed. There was no regular system or ... of measurement. As years passed by and business ... became more complex, some standards of exchange ... necessary. As a result of this demand came standards of ... of quantity, time, and money. Each of the dif- ... nations had its own system. For length, the length of ... of the body was generally chosen as the unit. For ... that of some particular well-known object furnished

There are in use in civilized countries today two general systems of measurement: one with which most of us are familiar, as used in every-day life, known as the *English;* the other used extensively in scientific work, known as the *Metric* system of weights and measures.

In the English system the standards have been arbitrarily chosen and named. The division and subdivision of these standards has been haphazard and irregular, with the result that we have a very mixed up system, difficult to learn. As an example of this irregularity, we have as the unit of length the *yard,* divided into three *feet,* each foot being divided into twelve *inches.* Division of the inch into halves, quarters, eighths, sixteenths, thirty-seconds, etc., furnishes the first semblance of regularity.

In weighing, the same confused condition exists. Not only is the common division of the unit (the *pound*) irregular, but the pound is divided in three different ways, according to the kind of substance to be weighed. We have avoirdupois weight for common articles, apothecaries' weight for drugs, and troy weight for valuables such as metals and precious stones. Each has its separate independent set of divisions.

In the metric system, one general scheme of division is followed, whatever the character of the substance measured. There is a standard of length, of area, and of weight. When amounts other than the standard are to be considered, the decimal or tenths system is employed. This metric system was devised by a committee appointed by the Assembly of France at the time of the French Revolution. It was an attempt to bring the nations of Europe to accept one common system of measurement in order to bring about uniformity. It is at present adopted by nearly all these nations. In England and Am[illegible] [illegible]ld

English system is still used in business, although the metric system is employed almost exclusively in science.

In order that the unit of length might be a fixed quantity that could be duplicated at any time, those in charge decided to take one ten-millionth of the distance from the equator to the pole, along the meridian that passed through Paris. A platinum-iridium bar of this length was made and is kept at Sevres, near Paris, at the Bureau of Weights and Measures. It has since been found that this bar is not exactly equal to the length intended, so that there is really no means of duplicating it exactly if it should be lost or destroyed. It is called a *meter,* and is equal to 39.375 inches in length.

Given the standard of length, the meter, one-tenth of it is called the *deci*-meter; one-tenth of a decimeter is called a *centi*-meter; one-tenth of a centimeter is called a *milli*-meter. Ten meters make a *Deka*-meter; one hundred meters make a *Hekto*-meter; one thousand meters make a *Kilo*-meter.

In measuring area we have square centimeters, square decimeters, square meters, etc. For measuring volume we have cubic centimeters, cubic decimeters, cubic meters, etc. Just as in the English system we have the *quart* for measuring liquids, so in the metric system we have the *liter*. The liter, however, is regularly connected with the decimal system, being equal to a cubic decimeter, which equals one thousand cubic centimeters. One liter equals 1.057 quarts. The quart and liter are thus very nearly equal, the liter being only about a twentieth larger.

In the system of weighing, the unit is the *gram,* which is the weight[1] of one cubic centimeter of water at a temperature

[1] To be more exact, the term mass or quantity of substance should be used here. The mass of anything, such as the piece of platinum-iridium used as the standard of weight, is the same wherever it may be carried. Its weight varies on different parts of the earth's surface, owing to the difference in the attractive force of the earth. This difference is very slight, however, so that for our purposes it is sufficient to say weight, where mass might be more properly used.

of 4° Centigrade or 39.2° Fahrenheit. At this temperature, as will be shown later, water is most dense. As this weight is very small, being equal to about one-thirtieth of an ounce, the standard is a piece of platinum-iridium metal that weighs one thousand times as much, called a *Kilogram*. This is also stored with the Bureau of Weights and Measures, and is equal to about 2.2 pounds.

Amounts smaller than a gram are prefixed by *deci, centi, milli,* as in the case of the meter. For the sake of convenience in writing, abbreviations of metric and English terms are used. The following table shows these abbreviations and the equivalents in the two systems:

1 meter (m.) = 1.094 yards (yd.) = 39.37 inches (in.)
1 centimeter (cm.) = .3937 inch
1 kilometer (km.) = .6214 mile (mi.)
1 square meter (sq. m.) = 1.196 sq. yd.
1 square centimeter (sq. cm.) = .1550 sq. in.
1 cubic meter (cu. m.) = 1.308 cu. yd.
1 cubic centimeter (c. c.) = .061 cu. in.
1 liter (l.) = 1.057 quarts (qt.)
1 gram (g.) = 15.44 grains (gr.) = .0353 ounce (oz.)
1 kilogram (kg.) = 2.204 pounds (lb.)
1 foot (ft.) = 30.48 cm.
1 yard (yd.) = .914 m.
1 quart (qt.) = .9463 l.
1 ounce (oz.) = 28.35 g.
1 pound (lb.) = .4536 kg.

CHAPTER II

HEAT

Effects of Heat upon Substances.
    Expansion, Thermostat, Thermometers.
Heat Measurement.
    Heat Capacity, Specific Heat.
States of Matter.
Change of State.
    Fusion and Freezing.
    Vaporization, Evaporation, Boiling, and Condensation.
Water Vapor in the Atmosphere.
    Dew, Frost, Humidity.
Heat Transfer.
    Sources of Heat.
    Convection. Heating Systems.
    Conduction.
    Radiation.
Waves.
Theory of Heat and Light.

6. **Heat Ever Present.** Probably the commonest form of energy in the household is *heat*. We must utilize it in the preparation of our food and as an aid for cleansing purposes. It is essential to human existence, for we are kept alive by the heat generated in our bodies from the food which we eat. We are familiar with it in many ways—the fires that burn in our stoves and furnaces; the sun that beats down upon us by day; the burning lamp and the electric light bulb, all give off heat that is apparent to our sense of feeling. In fact, it is only

through the sense of feeling that we are aware that there is such a condition as heat. We frequently try to determine the degree of heat by means of this sense, and many times fail to get an opinion that agrees with that of another person. The reason for this is that our temperature sense depends upon the temporary condition of the skin at the time. This condition depends upon where we have been previously or upon the amount of exercise we have been taking. It frequently happens that two persons coming into a room do not feel the same. The one coming from a much cooler place feels warm, while the other coming from a warmer place feels cool. Cold water from the faucet feels hot to a person whose hands are very cold.

Because the body is not an accurate indicator of how hot or how cold an object is, we must resort to other means of determining temperature. Such means lie in the effects of heat upon something other than the human body.

7. **Effect of Heat upon Objects.** Whenever heat is applied to an object, one or more of the following effects may take place: (1) there may be a rise in temperature (the object becomes hotter); (2) there may be expansion (an increase in volume); (3) there may be a change of state (from solid to liquid, or liquid to gas); (4) there may be an increase in outward pressure on the walls of the containing vessel; (5) there may be a change in its characteristics. As examples of each case, we have for expansion the overflowing of the water in a tea kettle if it is completely filled with cool water and placed over the fire; for change of state we have the melting of ice to form water, or the boiling of water to form steam; for increase in outward pressure we have the steam escaping from a covered kettle; for the change in characteristics we have the thinning of molasses and the softening of sealing wax.

EXPANSION EFFECTS

8. Expansion of Solids. The expansion effect upon solids may be shown as follows: Figure 1 represents a ball and ring, both made of brass, the inside diameter of the ring being just equal to the diameter of the ball as long as both are at the same temperature. If the ball is heated considerably, it will be found that it will no longer pass through the ring. If the ring also is heated, the ball will now pass through.

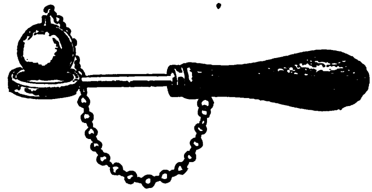


FIG. 1

Figure 2 represents a bar of iron, one end of which rests firmly against the left support. The other end touches one end of a hinged pointer. Any movement of the right end of the rod causes the pointer to rise or fall. If heat is applied, the pointer will rise, showing that the rod is expanding in length. Upon cooling, the pointer will fall back to its former position, showing that the contraction is equal to the expansion.

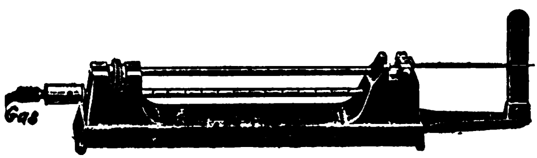


FIG 2.—THE POINTER RISES WHEN THE BURNING GAS HEATS THE BAR

Concrete sidewalks must be laid in sections, with spaces between to allow for expansion. When not so laid, they have been known to buckle on hot summer days. There are spaces

between the ends of car rails in winter, while in summer the ends fit snugly. The metal girders of buildings are held firmly together by rivets which are put into the holes red-hot and the small end is hammered out around the edges of the hole, thus forming a double head. The rivets on cooling contract and hold the plates tightly together. The glass chimney of a lighted lamp is sure to crack if a drop of water falls upon it, owing to the great contraction on the spot cooled by the water.

9. Unequal Expansion of Different Substances. All solid substances are not affected equally by equal rise in temperature.

Table of expansion rates. The numbers of the following table show what portion of its original length a piece of each substance will increase when its temperature is raised one centigrade degree:

Iron,	.000011	Zinc,	.000029
Brass,	.000018	Pine,	.000006
Glass,	.000009	Marble,	.000008
Platinum,	.000009	Copper,	.000017
Aluminum,	.000023	Tin,	.000022
Quartz,	.0000005		

Brass, for instance, expands more than iron when it is heated the same amount. If two straight pieces of metal (Fig. 3), one of brass and one of iron, of equal length, are riveted together in several places to prevent the slipping of one over the other or bulging, and this compound

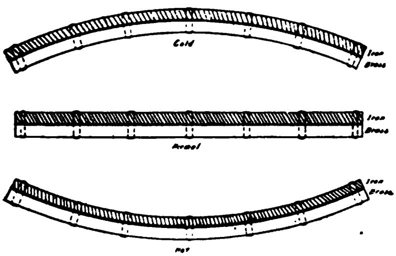


FIG. 3.—TEMPERATURE CHANGES AFFECT BRASS MORE THAN IRON

bar is heated, it will soon become curved, with the *brass* on the *outside*. If now cooled back to the original temperature, the bar will again become straight. If further cooled, however, it will be found to curve with the *iron* on the *outside*. The brass becomes *longer* (expands more) than the iron on heating, and therefore takes a position on the outside of the curve; while on cooling it becomes *shorter* (contracts more) than the iron, and therefore takes a position on the inside of the curve.

10. Thermostat. This appliance is for the purpose of keeping a room at even temperature by regulating the heat supply. There are two systems in general use, the electric thermostat being oftener seen in homes, and the compressed air type in large buildings. In the electric system the dampers regu-

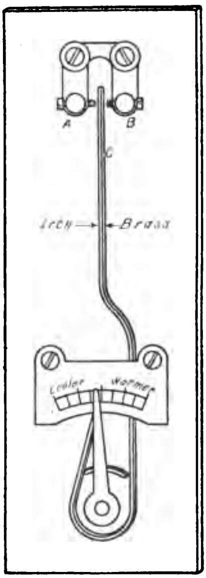


FIG. 4*a*

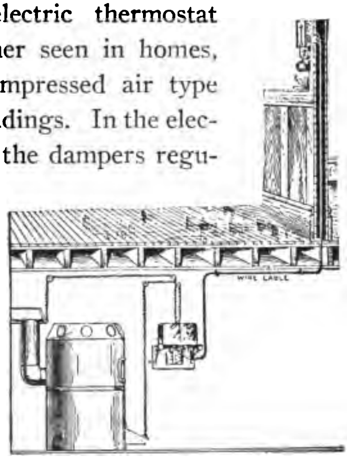


FIG. 4*b*

ELECTRIC THERMOSTAT

lating the drafts of the heater in the cellar are operated through a magnet which the thermostat brings into action. The effect is either to check or to force the fire in the heater. Which of these two effects will take place depends upon whether the compound

bar *C* (Fig. 4) is in contact with *A* or with *B*. If the room is too hot, the bar bends to the left, touching *A*. This completes an electric circuit that causes the fire to be checked. Likewise, if the room is too cool, the bar tends to straighten out, and the circuit is completed through *B*. This results in an increased draft and more heat. The figure shows the thermostat and the circuit through which the mechanism in the cellar operates the dampers (Fig. 4*b*).

A glance at the table shows that different substances are not affected the same amount by equal temperature rises, but there are two that expand practically the same on equal heating; these are glass and platinum. This fact makes platinum the *only* metal that can be used to connect the outside wires of the electric wiring circuit with the carbon or tungsten filament of our modern incandescent lamps. Since they are sealed into the glass hot, the wires and glass upon cooling contract equally, and the wires are just as tight-fitting hot or cold. Any other metal would contract more than the glass and thus be loose, and allow air to get into the bulb. The presence of air would cause the filament to burn out and thus become useless.

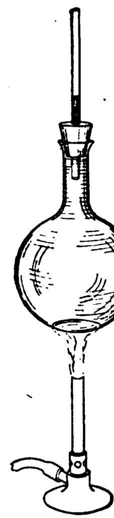


FIG. 5

11. Expansion of Liquids. The expansion of liquids may readily be shown by fitting a glass tube into a hole in the stopper of a flask and filling the flask and part of the tube with water (Fig. 5). On being heated, the liquid will rise in the tube. Different liquids, such as alcohol and mercury, may also be used, when it will be found that they do not expand equally, with the same temperature rise.

12. Expansion Effect Utilized in Determining Temperature Changes. Inasmuch as such substances as mercury, alcohol, and metals expand when heated and contract when cooled, it is possible to take advantage of this by properly arranging the substance to indicate the changes. Figure 6 represents a metallic thermometer in which the compound bar of brass and iron has one end *B* securely fastened to the support,

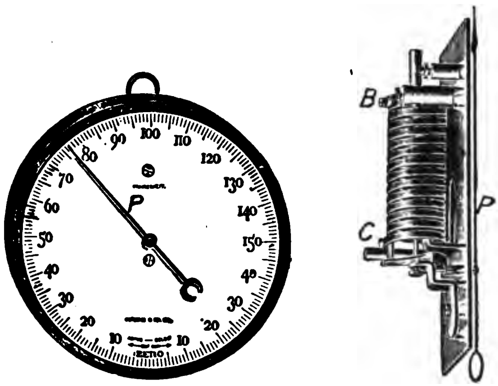


FIG. 6.—METALLIC DIAL THERMOMETER

and the other end *C* is free to move. This end is connected to a pointer *P* which rotates about its axis. When the temperature rises, the metal bar tends to straighten and the pointer is turned to the right. When the temperature falls, the bar curves more. If the scale is marked according to some accepted standard, a thermometer is the result, and the pointer indicates the temperature.

13. Liquid Thermometers. Commoner than the metallic thermometers, however, are those made by the use of some liquid such as mercury or alcohol. In these (see Fig. 7) a glass tube has a thin-walled bulb blown on one end. The open end

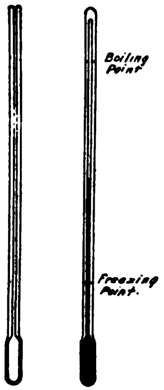


FIG. 7

is drawn out by melting the glass. The bulb is filled with mercury or alcohol, and is then heated. When the mercury reaches the top, the open end is sealed by melting the glass there, and the bulb is allowed to cool. As the mercury or alcohol cools, it contracts into the bulb, and the upper end of the column moves downward until the contraction ceases, *i. e.*, until the liquid becomes the same temperature as the surrounding air. Such a piece of apparatus is good only for comparing the temperatures of different objects or of the same object at different times.

14. **Graduation of Thermometers.** To make the above mentioned tube *indicate* temperatures, it must be marked and graduated according to some accepted standard. There are two such standards in general use now: the commoner one, as seen in most households, called the *Fahrenheit,* and the other, used almost exclusively in science, called *Centigrade*. They differ only in the manner in which they are marked to indicate the intensity of the heat. Both employ the same methods in securing the so-called *fixed points.* These are the places on the tube where the liquid comes to rest when the bulb and tube are immersed (1) in melting ice and (2) in steam under

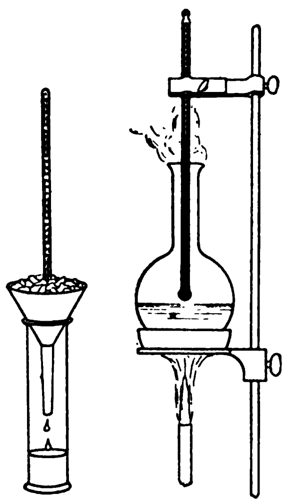


FIG. 8—MARKING THE FIXED POINTS

ordinary atmospheric conditions (called standard conditions) (Fig. 8). Such points are known as the *melting point* and *boiling point* of water, temperatures which are the same the world over.

15. Identity of the Fixed Points on the Different Scales. As far as the location of these points (freezing and boiling) is concerned, the two thermometer scales are the same; but as for the *numbers* representing them on the scale (such numbers serving as a simple indicator of temperature), the scales differ. The freezing point on the Centigrade scale, which represents exactly the *same degree of heat* as on the Fahrenheit scale, is 0 (Fig. 9), while on the latter scale it is 32. The boiling point, representing exactly the same degree of heat on both, is on the Centigrade scale marked 100 and on the Fahrenheit 212.[1] These numbers, since they stand for certain degrees of heat, are called *degrees*. Having located the degree marks for the freezing and the boiling temperatures of water, the space on the tube that lies between them must be divided into a number of equal parts to represent intermediate degrees of heat. If a certain heat addition to the bulb causes the mercury to rise a certain distance up the tube, a double heat addition will produce twice as much rise. The space on the tube between freez-

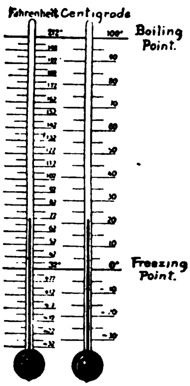


FIG. 9

[1] **Reason for the peculiar F. numbers.** The probable explanation for the odd numbers 32 and 212 for freezing and boiling point on the Fahrenheit scale is that when Fahrenheit devised his scale, the coldest thing known was a mixture of salt and ice, which he called zero. The temperature of the human body was known to be pretty constant, and he called this 100 degrees. It has since been shown that the temperature of the salt and ice mixture depends upon the proportion of each taken. As a result, some change in the zero marking has come about, bringing the temperature of the body to 98.6. Freezing and boiling water bring readings of 32 and 212 on such a scale.

ing and boiling on the Centigrade scale is divided into 100, and on the Fahrenheit scale into 180 equal divisions.

16. Plus and Minus Readings. Since the freezing point on the Fahrenheit scale is 32°, zero on this scale is *lower* than freezing; in fact, 32 Fahrenheit degrees lower. Now, inasmuch as we meet with conditions when the temperature is lower than 0° C. and 0° F., such degrees of heat are called *minus* (—), as contrasted with temperatures above 0°, which are called *plus* (+).

In connection with this use of the plus and minus signs to indicate temperature above and below zero on either Fahrenheit or Centigrade scale, it must be borne in mind that it is possible to have a temperature which is *minus* on the Centigrade scale and *plus* on the Fahrenheit scale; this is because the freezing point is *not* zero on both scales. A temperature of 0° F. would register nearly —18° C.

—5° C. and 23° F. are both *below* freezing, —5° C. is *below* zero C., whereas 23° F. is *above* zero F.

—20° C. and —13° F. are both *below* freezing and both *below* the zero of each scale.

17. Changing from One Scale Reading to the Other. Owing to the fact that one is often likely to meet a Centigrade as well as a Fahrenheit temperature, it is well to know how to find one when the other is given. In order to find the equivalent temperature on the scale, it is necessary to bear in mind (1) that the fixed points, freezing temperature (0° C. and 32° F.) and the boiling temperature of water (100° C. and 212° F.), are marked differently; they do, however, represent exactly the same heat intensity, as evidenced by the distance the mercury rises up the tube in expanding from the lower to the higher temperature; (2) that 100 Centigrade degrees represent exactly

the same heat change (rise or fall) as do 180 Fahrenheit degrees. A change in temperature of one Centigrade degree is equal to a change in temperature of $\frac{9}{5}$ ($=\frac{180}{100}$) of a Fahrenheit degree; a change of one Fahrenheit degree is equal to a change of $\frac{5}{9}$ ($=\frac{100}{180}$) of a Centigrade degree.

By substituting the given temperature in either of the following formulas, the desired equivalent temperature on the scale may be easily calculated:

$$C.^\circ = (F.^\circ - 32) \times \tfrac{5}{9}$$
$$F.^\circ = \tfrac{9}{5}\, C.^\circ + 32.$$

In using these formulas bear in mind that the temperature of reference in all cases of changing from one scale reading to the other is the freezing temperature of water. The first step is to find how many degrees the given temperature is away from freezing.

18. Uses of Thermometers. Thermometers have many uses in the household other than the common one of indicating the temperature of the air in a room or out of doors. Most up-to-date cooking stoves have metallic thermometers on the oven door to indicate the condition for baking and roasting different articles of food (Fig. 10). A thermometer should be used in the making of candies, if one expects to have the same results each time. The determination of the temperature of a bath should not be left to the feeling of the hand, or even of the elbow. Particularly does this apply to baths given for medicinal purposes, and to baths for babies, whose skin is so much more tender than the mother's hand or elbow.

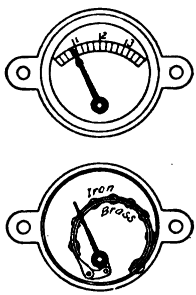


FIG. 10.—STOVE HEAT INDICATOR

19. Clinical Thermometers. One of the most valuable uses of the thermometer is in medical practice, as the means of determining the degree of bodily temperature. This in all normally healthy persons is 98.6° F. Any considerable deviation from this temperature is an indication of bodily disorder, usually a fever, which is accompanied by a higher temperature than normal. About the first thing a physician does when there is any indication of feverishness is to take the temperature of the patient. This is done with a so-called *clinical* thermometer (Fig. 11), which is different from ordinary ones in three ways: first, the scale reads only from 94° to 110° F., with a special

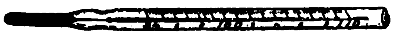


FIG. 11.—CLINICAL THERMOMETER

mark at 98.6°; second, the bore of the tube is very small; and third, near the bulb there is a narrowing of the tube up and down which the mercury moves as it expands and contracts. The purpose of this last is to prevent the mercury from passing too readily back into the bulb after it has registered the temperature of the patient. Were it not for this, the physician would have to "read the thermometer" when it is in the mouth, as otherwise the mercury in the thermometer would contract and register a lower temperature by the time he read it. The narrowing in the tube cuts off the mercury column from the mercury on the bulb side, so that it does not return to the bulb and the reading may be taken at any time. The mercury must be forced back into the bulb by shaking until its level is below 98°, before another temperature is taken.

20. Exceptional Expansion of Water. Water forms an exception to the general rule that the addition of heat to any-

thing causes expansion, and the removal of heat causes contraction. It does follow this rule within certain limits. If it is cooled, it will contract until its temperature reaches 4° C. or 39.2° F. Upon cooling below these temperatures, instead of contracting, it expands until it reaches 0° C. or 32° F., when it freezes. Upon heating, the reverse takes place. That this exceptional characteristic should apply only to water is one of the great provisions of nature. For were it not so, our ponds and rivers would freeze solid during cold spells in winter and the fishes would die. As it is, it is not possible for the water at the bottom of a pond to become colder than 4° C. or 39.2° F.

For a better understanding of this fact, it is necessary to know the meaning of a new term, *density*. If a dish is just filled by a quart of cold water, which weighs 2 lbs., and this dish is then placed upon the stove, the water in expanding will overflow. When the water is hot, there will still be a dish *full* of water, but it is hot and weighs less than the original cold water, by an amount equal to the weight of the water that has overflowed. This hot water occupies exactly the same space or volume that the cold water did. It is therefore said to be *less dense* than the cold water. Even though the temperature may be the same, equal volumes of different substances weigh differently. A quart of mercury weighs more than a quart of water, as does also a quart of molasses. If either substance, molasses or mercury, is poured into water, it sinks to the bottom.

It is thus seen that denser liquids sink and less dense rise to the top. Such being the case, if a drop in temperature below freezing occurs in the air above a pond, the water at the top of the pond is first affected, cools off, contracts, and becomes denser than the water below it. It naturally sinks to the bottom, pushing up to the top the warmer water below. This water in

turn cools, contracts, and sinks. This process, which is a very slow one, goes on just as long as the water on top contracts upon cooling, namely, until it is 4° C. or 39.2° F. Further cooling, however, now brings about an expansion of the water on top, which, thus becoming *less* dense than the water below, stays on top and continues to cool until it reaches 0° C. or 32° F., when it freezes to form a layer of ice on top. Thus the water at the bottom does not get below 4° C. or 39⅛° F.

21. Pressure Effect When Heat Is Applied. Very serious explosions of kitchen ranges have occurred when people have started fires in stoves at times when the water in the pipes was frozen. The reason for this is that when the water in the water-back of the stove starts to expand there is no room for this to take place, as the pipes are clogged with ice. The tremendous pressure exerted by the water as a result of this expansion bursts the water-back. A similar result, more disastrous, occurs in a hot water heating system where the water has frozen and a fire is started.

Bulging walls of brick buildings are sometimes straightened by putting long steel bars through them and screwing nuts onto the ends. When the bars are heated by a gas flame, the nuts are screwed up tight. Upon cooling, the force of contraction pulls the walls together. If the bar referred to in Figure 2 has a piece of metal pushed through a hole in it at right angles to it (Fig. 12), the force of expansion of the bar when it is heated breaks the pin inserted and the pointer jumps upward. Similarly, if another piece is inserted and the bar shortened by screwing the nut at left so that the

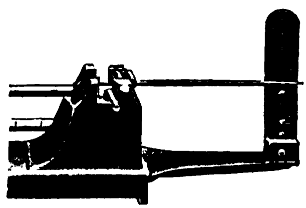


FIG. 12

pin rests snugly against the left-hand side of the slot when the bar is hot, the pin is again broken when the bar contracts on cooling.

Questions

1. Why is it that the zinc under a stove wrinkles when hot, if the edges are nailed down?

2. Why does the mercury level first fall in a thermometer, when it is placed in hot water?

3. Why do some kinds of wood crackle when they burn?

4. Why are not grate bars in furnaces fastened rigidly?

5. Describe the changes in volume that water undergoes when heated from 33° F. to 50° F.

6. Why is not water a good substance to use in a thermometer?

7. Which of the following temperatures are below freezing and which are below zero: 4° F., 4° C., —8° F., 40° F., —8° C.?

8. The temperature of a dish of water is raised 50 Centigrade degrees. What would have been the corresponding rise had a Fahrenheit thermometer been used?

9. A room with air at the temperature of 68° F. is said to be properly heated. What would be the temperature on a Centigrade scale?

10. Milk is pasteurized by heating it to 140° F. To what Centigrade temperature must it be heated?

11. Alcohol boils at 78° Centigrade. At what Fahrenheit temperature does it boil?

12. Sea water freezes at about 28° F. At what temperature Centigrade does it freeze?

13. Mercury freezes at —40° C. Could a mercury thermometer be used when the temperature is —45° F.?

14. Why is the bulb of a clinical thermometer long and cylindrical?

15. Why is the bore of a clinical thermometer so small?

16. Why should a pneumatic inkstand not be placed in the sunlight (Fig. 13)?

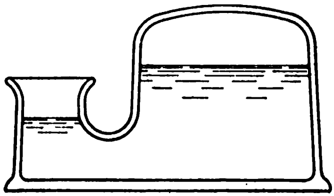


FIG. 13

HEAT MEASUREMENT

22. Heat Value in Substances. Most people, in buying fuels like coal, wood, kerosene, and gas, give little thought to the amount of *heat* that can be obtained from this fuel, but think only of the *quantity of material* they are getting. Different kinds of coal vary greatly in their heat-producing values. For this reason many companies that buy large quantities of coal require in their contracts that the coal shall give a certain amount of heat per ton weight. In some coal there is a large percentage of incombustible substance, which forms the ashes in our stoves and furnaces. This idea of heat value is a very important one also in connection with the food we eat, for food is the fuel for the production of body heat.

23. Heat Exchange—Warming and Cooling. In order to understand the idea of such a thing as *heat quantity*, which is not represented by some object, as in the case of the yardstick for measuring cloth, the quart measure for milk, the pound

weight for sugar, etc., there is one fundamental principle that must be thoroughly understood. Whenever we feel a desire to get warmer, our first thought is to go to a place that is of higher temperature, whether it be a warmer room or a fire. The reason that the result thus sought is attained is that whenever two substances of different temperature come together, the cooler one heats while the other cools; the first rises in temperature while the second undergoes a fall in temperature. How much heat change from the warmer to the cooler takes place depends upon how great is the difference in temperature between them, increasing with the greater difference. The heat cannot be seen or handled. That there is a change at all is evidenced only by the *change in temperature* of the objects. To measure heat, then, we must resort to an indirect means, namely, its effect on some standard accepted substance. This substance is water, and the unit in which the heat is measured is the amount that will raise the temperature of one gram of water through one Centigrade degree. Such a unit is called a *gram calorie,* or more simply *calorie.*

Since it takes one calorie to raise the temperature of one gram of water one Centigrade degree, it will take twice as much to raise it 2 Centigrade degrees, namely, 2 calories. If, on the other hand, 2 g. of water are taken, there is twice as much substance for the heat to be distributed in, and therefore it will take 2 calories to raise 2 g. of water one Centigrade degree. To raise 5 g. of water 10 degrees will take 50 calories, and so on. The number of calories absorbed is equal to the *number of grams of substance times the number of Centigrade degrees change in temperature.* If the above mentioned weights of water are cooled, the same respective amounts of heat will be given out.

Since a Fahrenheit degree is only $\frac{5}{9}$ of a Centigrade degree,

it requires only $\frac{5}{9}$ as many calories when the temperature change is measured in terms of Fahrenheit degrees.

24. **Heat Capacity.** A pint of water placed in a pan will heat much faster than a quart of water placed in another pan, if both are put on a hot stove side by side. Also a pound of molasses will heat faster than will a pound of water. In these two cases we are dealing with a situation that shows us that it makes a difference how much of a substance we use, and also what the substance is, as to the temperature effect produced upon it by equal amounts of heat; for in both of the above cases each of the two pans receives an equal amount of heat (number of calories) from the fire. In the first case the *weights* are *different,* but the *substance* the *same;* in the second case the *weights* are the *same,* the *substances different.* The two substances in each case are said to have a different *heat capacity;* that is, they require different amounts of heat to raise the temperature of each one Centigrade degree.

25. **Specific Heat.** Substances other than water require different amounts of heat to raise one gram of them one Centigrade degree. The number which represents the number of calories required to raise *one gram* of any substance through one Centigrade degree represents the *specific heat* of that substance.[1]

The difference between *specific heat* and *heat capacity* is twofold: (1) specific heat is expressed by a number, while heat capacity is a number of calories; (2) specific heat has to do with *one gram* of a substance, while heat capacity has to do with the *whole substance.* Thus one substance may have a different heat capacity from another, though of the same material, because

[1] The term specific is here used to mean special heat with reference to a standard, water, 1 gram of which requires 1 calorie to raise it one Centigrade degree.

different in weight; also when of the same weight, because of different material.

26. Table of Specific Heats.

Water,	1.00	Sand,	.19
Copper,	.091	Olive oil,	.31
Alcohol,	.62	Wood,	.65
Iron,	.113	Lead,	.031
Soapstone,	.21	Glycerin,	.55
Glass,	.198	Marble,	.21
Aluminum,	.214	Salt,	.17
Tin,	.055		

The high specific heat of water makes it most useful in hot water bottles. For the same reason soapstone discs are used in preference to iron in fireless cookers.

27. Experiments to Show Different Specific Heats. That different substances differ in their specific heat may be shown by taking balls of the same weight but of different metals. These are heated to the same temperature by immersion in hot oil, and then placed on a thin disc of paraffin wax (Fig. 14). The one that gives off the most heat on cooling will melt the wax most, even passing through. The others will sink to different depths in the wax, in proportion to their respective specific heats.

FIG. 14

If we place in separate test tubes 20 g. respectively of lead shot, iron filings, aluminum filings, and copper filings, and heat them in the same beaker of boiling water, they will all in time come to the same temperature as the water. If they are now poured into separate beakers, each containing 100 g. of water at the same temperature, we shall find that the water will be heated up unequally, the aluminum producing the greatest effect, the iron next, then the copper, and last the lead. This is because of their different specific heats.

28. Determination of Specific Heat. The method employed in finding the specific heat of an insoluble substance such as iron depends upon the fact that when two substances of different temperatures are brought together the warmer one *loses* as much heat as the cooler one

gains, both finally reaching the same temperature in the process. If 100 g. of water at 80° C. are mixed with 100 g. at 20° C., the resulting temperature will be halfway between, namely, 50° C. The warm water loses $100 \times 20 = 2{,}000$ calories, while the cold water gains $100 \times 20 = 2{,}000$ calories. If we use 100 g. at 80° and 50 g. at 20°, the result will be a temperature of 60°, since the cold water rises 2° for every degree the warm water cools off, as there is only half as much of it. Here $100 \times 20 = 2{,}000$ calories for the hot water and $50 \times 40 = 2{,}000$ calories for the cold water.

If now we put a piece of hot iron in the cold water, knowing that the iron will give up as much heat as the cold water absorbs, we can calculate how much heat one gram of the iron gives up in cooling one Centigrade degree. For example, suppose 200 g. of iron at 100° C. are put into 200 g. of water at 15° C., with resulting temperature of 23.6° when stirred together. The cold water has taken up $200 \times (23.6 - 15)$ calories. This is equal to $200 \times 8.6 = 1{,}720$ calories. The 200 g. of iron have given this out in cooling from 100° C. to 23.6° C., which is 76.4 Centigrade degrees. One gram of iron in cooling 76.4 degrees has given out $1{,}720 \div 200 = 8.6$ calories. One gram in cooling one degree has therefore given out $8.6 \div 76.4 = .112$ calorie. This is the specific heat of iron.

STATES OF MATTER

29. We are all familiar with water as ice, water, and steam. In these three conditions we find water representing the three *states* in which substances may exist if conditions are right. These three states are known as the *solid, liquid,* and *gaseous.* In the case of most substances we are familiar with them in one form only, sometimes two. In many cases, a substance commonly appearing as a solid or a liquid may be turned to the liquid or gaseous state by the application of heat alone. Examples of this are paraffin wax, sugar, butter, sulphur, alcohol, ether, kerosene.

30. **Change of State—Fusion and Freezing.** A lump of ice will not stand long in a warm place without turning to water. We also know that water will turn to ice when the temperature

falls below a certain point. This process of any substance changing from a solid to a liquid state is called *melting* or *fusion*. The reverse process is called *freezing* or *solidifying*. Scarcely any two substances melt at the same temperature, as the table shows.

31. Table of Melting Points.

	Temperatures Centigrade		Temperatures Centigrade
Ice,	0°	Gold,	1,060°
Mercury,	—38.8°	Copper,	1,068°
Butter,	33°	Iron,	1,100°
Lard,	33°	Platinum,	1,730°
Paraffin,	38–52°	Zinc,	419°
Alcohol,	—130°	Tungsten,	2,800°
Sulphur,	114°	Tantalum,	2,300°
Tin,	232°	Solder,	190°
Lead,	328°	Fusible metal,	70°
Aluminum,	655°	Carbon,	Sublimes first
Silver,	955°		

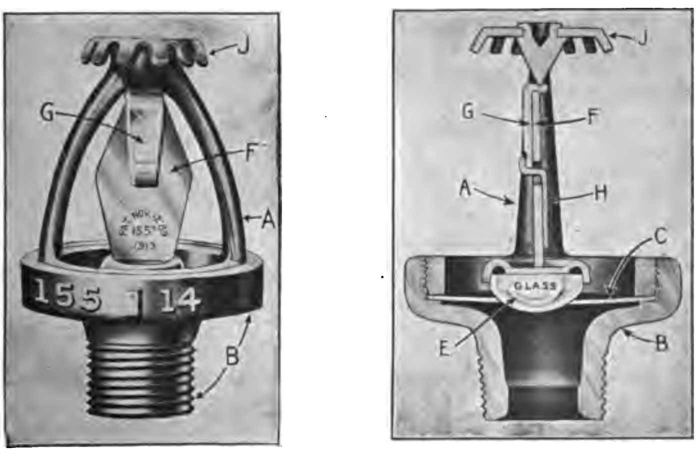
32. If we take the temperature of the ice at the time melting starts, we find it is 0° C., at which temperature it remains during the whole time of melting. Nearly all substances act in this manner when melting. Some substances, like sealing wax and butter, do not remain at the same temperature, but get warmer as the melting goes on. The general rule is for a given substance to melt or freeze at a definite temperature under ordinary conditions. This temperature is called the *melting* or the *freezing point*.

33. **Effect of the Presence of an Impurity.** On days when the temperature out of doors is so low that the ice on the sidewalks will not melt, we throw salt on it to make it melt. The

presence of salt causes the ice to melt at a temperature lower than its ordinary melting temperature. Likewise the presence of salt in water necessitates a lower temperature for the water to freeze. Other solids and liquids are also affected by the presence of an impurity, which in all cases lowers the melting or the freezing temperature.

34. **Alloys.** Whenever the plumber wishes to mend a leaking water pipe he uses lead solder, not lead. This solder is made up of one-half lead and one-half tin, and melts at 190° C.—a much lower temperature than the melting point of lead. Because of this, the lead pipe is not melted by the hot solder. Alloys are composed of two or more metals in varying proportions. Pieces of gold are soldered with an alloy of gold, silver, and copper; silver articles are soldered with an alloy of silver and copper.

35. **Fusible Metal.** By using the proper proportions of certain metals, alloys of very low melting points may be obtained; for example, one composed of Bismuth 7 parts, Lead 4 parts,



a Fig. 15 *b*

Tin 2 parts, and Cadmium 1 part, melts at 70° C. The bowl of a spoon made of this alloy will melt when placed in hot tea or coffee.

36. Automatic Fire Sprinkler. In the automatic sprinkler (Fig. 15) the glass plug *E,* held in place by the bar *F, H, G,* fits tightly into the hole of *C,* thereby preventing water coming through *C* from below. *G* and *H* are soldered to *F* by means of a low fusing point alloy. Should a fire start near a water pipe fitted with such a sprinkler, the alloy, when heated to 155° F., melts, and the pressure of the water below is now sufficient to force the pieces *H* and *G* away from *F*. The water, no longer held in by the plug *E,* rushes up, strikes the umbrella-like tip *J,* and is sprayed in all directions. In buildings protected by such automatic sprinklers, pipes are run close under the ceilings of the rooms and the sprinklers are placed on them at frequent intervals.

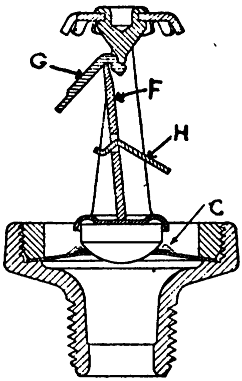


FIG. 15*c*

37. Effect of Pressure upon Melting Point. If we walk along the sidewalk when there has been a light fall of snow, and the temperature is slightly below freezing, a cake of ice frequently forms on the heels of our shoes. It is this piece of ice that sometimes drops off the heels after we have been in the house a short time. The snow has in some way been turned into ice. Now water is a substance that expands when it freezes, and *vice versa,* ice contracts upon melting. If we look upon the melting of ice as a process of *contraction,* without considering the *heat* side of the matter, it can be seen that if we apply pressure alone to ice we may bring about the same result that heating will do, namely, turn ice to water. By the pressure of the heel we are helping the ice (in the form of snow) to contract. As a result, the snow melts at a lower temperature than it otherwise would. When

we lift the heel we remove the pressure that caused the contraction, and the water at once expands to the solid state, since the surrounding air is too cold for it to remain a liquid.

Summing up: (1) most pure crystalline substances melt and freeze at definite temperatures; (2) while melting, the solid substance stays at the same temperature; (3) the presence of an impurity which will dissolve in the substance lowers the melting point; (4) the application of pressure to a substance that contracts on melting lowers the melting point. Most substances *expand* on melting. Cast iron, type metal, and water,

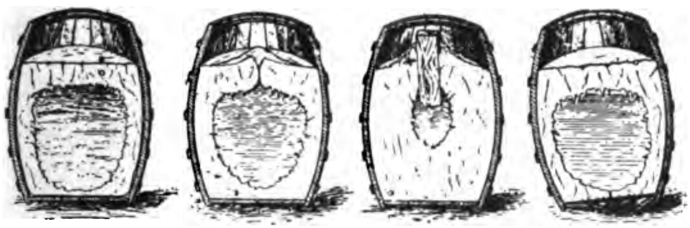


FIG. 16.—WATER EXPANDS WHEN IT FREEZES

on the other hand, *contract* on melting, but expand when solidifying (Fig. 16). It is this characteristic of iron and type metal that makes them useful for casting purposes.

38. Heat of Fusion. Ice is put into the refrigerator for the purpose of cooling the food there, that is, absorbing the heat given out by the food. The temperature of the ice during the process remains the same, but the ice melts, and must be replenished from time to time. Evidently the process of melting is one that requires heat *without a temperature effect resulting*. The quantity of heat absorbed by *one gram* of a solid substance in the process of melting is called the *heat of fusion*. In the case of ice it is 80 calories.

39. Determination of Heat of Fusion of Ice. This is done in much the same way as is the experiment for determining specific heat.

If 10 g. of ice at 0° C. are placed in 190 g. of water at 20° C. and stirred, the ice will first melt, forming 10 g. of ice water. The ice water will then be warmed to 15° C.

In this case the 190 g. of warm water have given up 190 × (20—15), or 950 calories. The 10 g. of ice water, warmed from 0° C. to 15° C., have absorbed 10 × 15, or 150 calories of these 950 calories, which leaves 950—150, or 800 calories used up in melting 10 g. of ice. One gram of ice then takes 800 ÷ 10, or 80 calories, to melt it.

40. Ice Cream Freezer. The absorption of heat that takes place when ice melts is taken advantage of in the ice cream freezer (Fig. 17), where, with a wooden outer pail, the inner metal can is surrounded by a mixture of salt and ice. The temperature of this mixture is much lower than the freezing point of the cream in the freezer. The salt on the ice makes it melt more readily. In the process of melting, the ice absorbs heat from the salt and whatever salt water may be already present. The presence of the mixture of colder salt, ice, and salt water around the cream in the center causes the cream to give up its heat to aid in the process of further melting the salt and ice mixture, with the result that the cream freezes.

FIG. 17

41. Just as solids in melting absorb heat without any temperature *rise*, so liquids after being cooled to their freezing point, in the process of freezing, give off heat to the surrounding air without any *fall* in temperature. For this reason tubs of water

in the kitchen near the water pipes on a very cold night tend to keep the water in the pipes from freezing, as the water in the tubs which is free to expand will freeze first, and in doing so will give out some heat to keep the pipes warm.

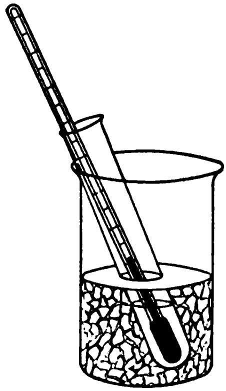


FIG. 18

42. Heat Evolved When Water Freezes. Let us take a test tube ⅓ full of water that has been boiled to remove the air. Into this put a thermometer and place the tube in a beaker containing a mixture of salt and ice (Fig. 18). If the tube is allowed to stand undisturbed, the temperature of the water should fall considerably below freezing. If now the tube is shaken or stirred, the water should begin to freeze at once, the temperature rising rapidly to the freezing point during the process. This shows that the heat of fusion is being given out. Sometimes it may be necessary to add a small particle of ice to start the freezing process.

QUESTIONS

1. Which will melt more easily, lead or tin?

2. Why does a hot water bottle stay warm so long?

3. Why is a soapstone disc better than an iron one in a fireless cooker?

4. Why do pipes burst in freezing?

5. Explain fully why water in a tub freezes before the water in pipes close by.

6. Explain why the volume of the ice cream obtained is greater than that of the liquid put into the freezer.

7. Explain the cause of the groove left by skates on the ice.

8. Why do people say that the frozen water pipes burst when they are thawed out?

9. What is wrong with the idea of wrapping ice in a blanket or newspaper in a refrigerator in which food is kept?

10. Why must coins be stamped, not cast, as is type metal?

11. In which will winter probably come later, a valley with a stream flowing through it, or one without a stream? Explain.

12. Why does breathing particles of frozen mist in winter hurt the lungs?

13. What is the object of the wooden strips on the dasher of an ice cream freezer?

14. Why is it poor policy to allow the salt water to drain off from the ice cream freezer much below the cover while freezing is going on?

15. Why is ice more effective than ice water in cooling a refrigerator?

16. Aluminum has a higher specific heat than copper. What is the objection to aluminum in place of copper for "soldering irons"?

Problems

1. Which requires a greater heat addition: to raise 50 g. of water from 20° C. to 65° C., or to raise 25 g. of water from 10° C. to 90° C.?

2. Which will give off more heat to the room: 500 g. of water at 90° C., or 2,000 g. of water at 60° C., if both are in a room the temperature of which is 20° C.?

3. If 2 liters of water at 90° C. are poured from a pitcher into a basin containing 2 liters of water at 10° C., to what temperature will the cold water rise?

4. What will be the resulting temperature if 4 liters of water at 80° C. are poured into 2 liters of water at 20° C.?

5. In which case will more heat be given out to the air in a room: (1) when 10 kilograms of water cool from 95° C. to 20° C.; or (2) when 30 kilograms of iron at 500° C. cool to 20° C.?

43. Change of State—Vaporization. All liquids before they will burn must be changed into a *gaseous* state. This explains why the wick of the kerosene lamp or the candle does not light at once when a lighted match is held to it. The heat is at first used to convert the substance into its gaseous state. This gaseous substance, in the case of things which we ordinarily find in the *solid* or *liquid* state, is called a *vapor,* as contrasted with a *gas* with which we are more familiar in its gaseous state.[1] Examples of vapors are the gaseous form of gasoline, kerosene, alcohol, paraffin, produced by heating them. Examples of true gases are oxygen, hydrogen, nitrogen.

Some substances turn to the gaseous state without first becoming liquids, as camphor, naphthalene moth balls; even ice does when clothes freeze dry.

The process of changing a solid or liquid substance into a gaseous state is called *vaporization.* This process may take place in two distinct ways; for instance, water in a pan may be made to disappear either by setting it aside, when the level slowly falls and the water quietly turns to vapor—a process known as *evaporation;* or the pan may be set on the hot stove, when the water soon heats up, becomes violently agitated, and turns to steam—a process known as *boiling.* The difference between these two processes is that evaporation takes place (1) slowly, (2) only on the surface exposed to the air; whereas boiling takes place (1) violently and rapidly, (2) throughout the liquid.

44. Evaporation. If the laundress wishes the wet, wrung-out clothes to dry as quickly as possible, she spreads them out on the line in a sunny, windy place, that the water in the clothes may be evaporated. She does this in order (1) to expose a

[1] While this distinction between a gas and a vapor is not complete, it is all that is needed to fulfill our purpose here.

large surface to the air into which the water vapor is to pass, (2) to get the clothes as warm as possible, and (3) to have the wind carry off the vapor as soon as it forms. Furthermore, if a pair of gloves have been washed with gasoline, they will dry faster than another pair washed with water, even though the two pairs hang side by side.

Four conditions thus affect evaporation:

(1) The character of the evaporating liquid.

(2) Surface exposed.

(3) Temperature.

(4) Removal of vapor when it forms.

Medicines and perfumery, which are generally alcoholic solutions, must be kept tightly corked to prevent the rapid evaporation of the alcohol.

45. **Boiling.** If a pan of cold water with a thermometer in it is placed over a fire and carefully watched, bubbles will soon be seen forming inside on the bottom and on the sides of the pan. These bubbles grow larger and finally break away from the pan, rising to the surface and quietly disappearing. They consist of air which was dissolved in the water and expanded because of the heat. After the air blisters have quite disappeared from the inside surface of the pan, a further rise in temperature produces a new phenomenon. Small blisters appear on the bottom of the dish where the heat is greatest. These blisters begin as slight mounds which rise and fall. As the temperature rises they become larger and more numerous, rising and falling over a large area of the pan bottom. A slight noise results from this. Further heating sets the bubbles free, only to disappear before they reach the surface; and upon still further heating, bubbles come to the surface and burst in the air as steam, and *boiling* goes on. The noise lessens when boil-

ing starts. Up to this point the thermometer has shown a steady rise in temperature, but when boiling goes on there is no further rise, the water boiling away during the process. The temperature, if atmospheric conditions are normal, will be 100° C. or 212° F.[1]

46. That other substances boil at different temperatures is shown in the following table of boiling temperatures:

	Centigrade		*Centigrade*
Water,	100°	Mercury,	357°
Alcohol,	78°	Sulphur,	444°
Ether,	37°	Kerosene,	185–200°
Gasoline,	45–60°		

47. **Boiling Point Affected by the Presence of an Impurity.** If some sugar is thrown into the water while it is boiling, there will be a violent disturbance at first; the boiling will then stop, and the water will rise above 100° C. before boiling will start up again. The further addition of sugar will raise the temperature of boiling still higher. This rise of the boiling point is proportional to the amount of sugar dissolved. Confectioners utilize this fact in determining the concentration of the boiling sugar solution.

48. **Expansion of Water When It Turns to Steam.** Water when it turns to a vapor (steam) at the boiling temperature occupies nearly 1,700 times as much space as when liquid. Thus there is enormous expansion going on during boiling, and the air above the water must be pushed aside to make room for the steam.

49. **Effect of Pressure on Boiling Point.** If we can help remove this air from the surface of the water by means of a

[1] If the water is very deep, as in a kettle nearly full of water, it will not boil at 100° C., but will require a higher temperature. The temperature of the vapor will, however, be 100° C.

so-called suction or vacuum pump, we can make the water boil more easily (Fig. 19), *i. e.*, at a lower temperature; and *vice versa,* by closing the outlet and making it more difficult for the steam to get out, we can make the water boil at a higher temperature.[1]

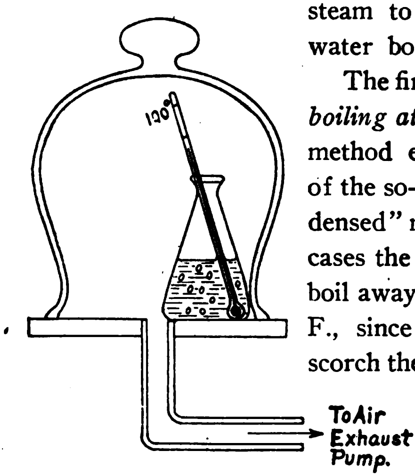


FIG. 19.—THE WATER BOILS AT A TEMPERATURE BELOW 100° C.

The first of these conditions is called *boiling at reduced pressure,* and is the method employed in the preparation of the so-called "evaporated" or "condensed" milks on the market. In these cases the water in the milk is made to boil away at a temperature below 212° F., since such a temperature would scorch the milk. The steam as it forms is continually pumped away to reduce the pressure on the surface of the milk.

On the other hand, a striking example of boiling at a higher temperature under increased pressure is shown in the case of a kettle "boiling over." In this case, a kettle of water which boils freely with the cover off will boil over when a close-fitting cover is placed upon it. The cover prevents the escape of the steam, which, pressing down on the water, causes the boiling temperature to rise a degree or so. At the higher temperature the steam coming from the water pushes outward harder, and finally the cover is pushed up, suddenly setting free the entrapped steam, which is followed by some of the liquid.

[1] This must not be confused with the well-known fact that water in a kettle with the cover on takes less time to be heated to its boiling point than it takes with the cover off. In such a case there is another phenomenon, called convection, which takes place in the air above the water, and which tends to keep the water cool.

This is due to the fact that with the sudden release of the pressure there is nothing to prevent the water from boiling violently, since it is at a temperature two or three degrees higher than is necessary for it to boil ordinarily. This extra heat in it is set free all at once, the temperature of the boiling water falling back to 212° after the cover is removed. The boiling over goes on only while the temperature is dropping, and ceases when 212° is reached.

FIG. 20

50. Pressure Cookers. Application of the fact that an increased pressure raises the boiling point of a liquid and the temperature of the resulting steam is made in the so-called pressure cooker, in which vegetables are cooked in a very short time by the use of a cover that is clamped to the kettle. There is a safety valve to allow the steam to escape if the pressure becomes too great. In this manner a temperature considerably above 212° F. is obtained (Fig. 20). In cooking vegetables a high temperature is what is sought. Gelatin is extracted from bones by cooking them under pressure.

51. Example of Cooking by Steam under Great Pressure. A most striking instance of this so-called *superheated* steam is the case of puffed wheat and puffed rice. The rice or wheat kernels are placed in strongly made cylinders and a cover is clamped tightly to the open end, and on this a pressure recorder is fixed. The cylinders are now heated to 350° F. Some of the water of the cereal is set free as steam and acts on the balance to cook it. When the pressure has become high enough, the clamp is suddenly released. In its superheated condition the balance of the water in the starch granules, when thus released from the great pressure, explodes into steam, and bursts the granules in the process.

52. Summing up:

(1) All liquids have a definite boiling temperature.

(2) The presence of a soluble impurity raises the boiling temperature.

(3) Increasing the pressure on the surface of a liquid raises the boiling temperature; decreasing the pressure lowers the boiling temperature.

53. Condensation—Change from Gaseous to Liquid State. We know that if we breathe on cold glass a mist (water) appears on the glass. Likewise water will appear on any cold object

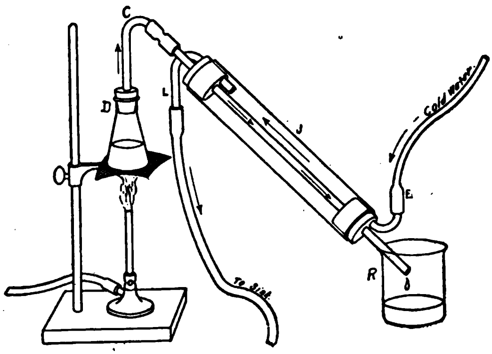


FIG. 21.—DISTILLATION

held near the spout of a teakettle of boiling water. In both cases the invisible water vapor has turned to visible water. This process is called *condensation,* just the reverse of vaporization. The cloud seen near the mouth of the spout of the kettle is due to the cooling and condensation of the water vapor, when it meets the cool outside air.

54. Distillation. Since different liquids boil at different temperatures, if two mixed liquids or a solution of a solid in a liquid are heated, the one boiling at the lower temperature will vaporize first. If this vapor is passed through a tube that is kept cool (Fig. 21), the vapor will condense and may be col-

lected. This process is known as *distillation*. If, for instance, a dirty solution of salt and water is boiled in the flask *D*, the water vapor must pass through the tube *C*. This tube is kept cool by water passing through an outer tube *J*, entering at *E*, and leaving at *L*. This cool water causes the vapor to condense and flow into beaker *R*. The salt and dirt remain in the flask, since they do not vaporize.

In the case of boiling hard water in a teakettle, a deposit forms in time on the inside of the kettle. This is due to the mineral substance that is left behind when some of the water is boiled away. Oyster shells are often put in the kettle for this deposit to form upon. If the steam formed in the process had been condensed, pure water, free from mineral, would have been the result.

Kerosene and gasoline are obtained from petroleum oil by the process of distillation. The gasoline, vaporizing at a lower temperature, boils first and its vapor is condensed. At a higher temperature the kerosene boils and its vapor is collected in the same manner.

Essential oils from flowers, as used in perfumery, are distilled at reduced pressure, as in this manner the full odor of the flower is preserved.

55. Singing of Kettle. The explanation of the noise described under the process of boiling (Section 45) can now be understood as due to the collapsing of the steam bubbles which formed first on the bottom. These steam bubbles were hotter than the water just above them, and were therefore condensed when they rose up into it. When they collapsed the water dropped down upon the bottom of the dish, producing a series of taps which, acting together, made the metal of the dish vibrate. Such a phenomenon occurs when the kettle "sings" or "simmers."

56. Heat of Vaporization. Just as ice in melting absorbs heat without its temperature rising, so water, in vaporizing, whether in the slow process of evaporation or in the rapid

process of boiling, absorbs heat without an accompanying temperature rise. This absorption is very apparent in the case of boiling, for the temperature remains the same during the process. In evaporation it is not so apparent. Such heat used to change one gram of any substance from the liquid to the gaseous state is known as *heat of vaporization.* For water it is 540 calories. When one gram of the vapor of any substance condenses back to the liquid state, this heat of vaporization, sometimes called *heat of condensation,* is given out to the surrounding air or to objects near, without any accompanying drop in the temperature of the liquid.

57. Applications of Heat of Vaporization. Many evidences of this heat of vaporization exist. A wet towel on the line is much cooler than a dry one hanging beside it. A flower pot with a wet plant in it is cooler than one with dry earth inside. The skin of human beings is cooler than the body temperature, owing to the evaporation of perspiration from the skin, which supplies the heat necessary for the vaporization to go on. A scald from steam is much worse than one from hot water, owing to the large amount of heat given up by the steam in condensing. Hot water merely cools off. Steam heat is much more intense than is hot water heat for the same reason.

Alcohol on the forehead, since it evaporates much more rapidly than the perspiration, makes one feel cooler. Gasoline not only makes one's hands cooler, but, by absorbing the perspiration, as well as itself evaporating, dries the hands. Water standing in a tumbler is cooler than water in a bottle beside it, because of evaporation.

58. Experiment to Show the Heat Absorption during Evaporation. Let us take a small dish of thin copper, placing in it a small amount of ether. If we now place the dish on a drop of water on a cork, and blow gently on the ether with a bellows, the dish will

soon be frozen to the cork. The ether in evaporating has absorbed the heat from the dish and the water so rapidly as to lower the temperature of the drop of water below freezing.

59. Determination of the Heat of Vaporization of Water. Suppose 5 g. of steam at 100° is condensed in 195 g. of water at 20° C. with a resulting temperature of 35.5° C. The cold water has taken up $195 \times (35.5 - 20) = 195 \times 15.5 = 3022.5$ calories. Of this the 5 g. of condensed steam has given out $5 \times (100 - 35.5) = 5 \times 64.5 = 322.5$ calories, in cooling down to 35.5 degrees. The balance, $3022.5 - 322.5 = 2700$ calories, has been given up by the 5 g. of steam in changing from steam to water. The heat given out by 1 g. is $2700 \div 5 = 540$ calories.

60. Heat Resulting from the Compression of a Gas. When air is pumped into a bicycle tire the pump barrel soon becomes quite warm. This heat is not due to friction between

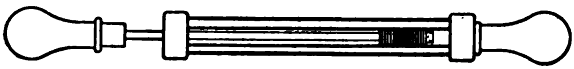


FIG. 22.—WHEN AIR IS COMPRESSED IT BECOMES HEATED

the piston and the walls, for the barrel does not become warm if we move the piston back and forth when the pump is not connected with the tire. The heat effect is due to the compression of the air. This heat effect may be strikingly shown by means of the apparatus called a fire syringe (Fig. 22), in which a tight-fitting piston is pushed rapidly into a cylinder the other end of which is air tight. A piece of very inflammable material put into the cup at the end of the piston is set on fire by the great heat evolved when the piston is pushed rapidly into the cylinder, thereby compressing the confined air.

When a gas is expanded a reverse effect takes place; the gas becomes cooler. This may be shown by allowing compressed air to pass from a tank and fall upon a thermometer bulb. If the air in the tank is at room temperature, there will be a drop in temperature shown on the thermometer.

61. Cold Storage and Artificial Ice. If gaseous ammonia is compressed sufficiently and then cooled, it can be turned into a liquid state. During the process, however, large amounts of heat both in compression and condensation are evolved. The compressed ammonia is cooled by passing cold water over the pipes in which it is to liquefy. The cooled liquid ammonia is now allowed to expand again through a valve into larger pipes that are surrounded by brine (salt water). In the process of turning back into the gaseous state, the ammonia absorbs from the brine the heat of vaporization of ammonia, which absorption lowers the temperature of the brine considerably below 32° F. If pans of water are placed in this cooled brine, cakes of ice will form. If, on the other hand, the brine is pumped through pipes arranged on the walls of a room, the heat of the room will be absorbed in warming the cooled pipes. Articles are thus kept cool as in a refrigerator where ice is used. This method of artificial refrigeration is known as *cold storage,* and is used nowadays in preserving eggs, butter, apples, fowl, meats, and other articles of food that would otherwise become unfit for use in a short time.

By using air which has been liquefied by a process of compression and cooling, just as the ammonia was treated, temperatures as low as —191° C. are obtained.

62. Artificial Skating Rinks. The ice in artificial skating rinks is formed by the use of ammonia as above described, the cold brine being pumped through pipes laid on the ground with a layer of water over them to the depth of 3 to 6 inches.

63. "Sunstroke," Fever, "Colds." "Sunstroke" is a condition in which the pores of the body fail to work normally, with the result that there is no perspiration to evaporate and thus cool the skin. The intense heat of the sun produces too great oppression and unconsciousness may result. In fever, the same failure of the perspiration to come

allows the heat to accumulate in the body, and the temperature of the body consequently rises. A fever is "broken" by bringing on perspiration. A "cold" is a form of fever, and is frequently relieved by a hot bath (which opens the pores of the skin) followed by a drink of hot lemonade, to bring on abundant perspiration. This, in evaporating, absorbs heat and relieves the internal congestion.

Questions

1. What is the fallacy in the terms "condensed" or "evaporated" milk?

2. How can the steam bubbles be distinguished from the air bubbles when water is heated?

3. What is the smoke that we see when a candle is blown out?

4. Explain why it is that a person is so hot in a fever, and why we seek to break the fever by bringing on a profuse perspiration.

5. Why does the "cloud" at the mouth of a teakettle disappear when a lighted candle or match is held beneath it?

6. Why does green wood sizzle when it burns?

7. Explain how sugar syrup is concentrated by boiling at the sugar refineries without the temperature becoming high enough to burn the sugar.

8. Explain how potatoes may be cooked (boiled) in ten minutes.

9. What is the object in using double boilers?

10. Explain the mist that forms on mirrors when we breathe on them.

11. What effect does the tightness of the cover have on the temperature of the water in the case of a "kettle boiling over"?

12. Why does a kettle "steam" before boiling?

13. Explain why water evaporates faster from a pan than from a bottle.

14. What would be the result if the spout of a kettle were corked?

15. Why do not the steam bubbles rise to the top when they first form in a kettle?

16. Why does steam form on the bottom of the kettle first?

17. Explain why it is a waste of gas to keep water boiling violently in cooking vegetables or cereals.

18. What two objects are sought in sprinkling the roads in summer?

19. Explain the "popping" of corn.

20. Explain the hissing noise when a red-hot poker or stove-lid lifter is held under cold water.

21. Why does the teakettle have a large base?

22. Why does an apple swell up when baked?

23. Why is a person likely to feel chilly when sitting in a draft in damp clothing?

24. Why does alcohol cool the forehead?

25. Explain why water inside a porous canvas bag, called a water bottle, is colder than water in a glass bottle.

26. Why is a scald from steam so much more painful and intense than one from boiling water?

64. Quantity of Water Vapor in Air—Effect of Temperature. Clothes dry more quickly in the warm kitchen than out of doors. Water on the pavements tends to evaporate much faster on the warm days of summer than on the cool days of winter. This is due to the fact that it is much easier for water to evaporate into air as the temperature of the air rises. We may for convenience liken the condition to that of alum in water. Much more alum will dissolve in *hot* than in *cold* water. If the water has dissolved all the alum it can take up, it is said to be

saturated. Any cooling of this saturated solution will result in a separation from solution of some of the alum, since at the lower temperature it takes less to saturate it. In the same way, when all the water vapor possible has been taken up by a given volume of air, the air is said to be saturated, and no more water will evaporate into it.

65. Quantity of Water Vapor in Saturated Air. Experiments have shown that a cubic foot of air saturated with water vapor at different temperatures contains the amounts indicated in the following table:

1.32 grains	at 20° F.
2.11 grains	at 32° F.
2.84 grains	at 40° F.
4.07 grains	at 50° F.
5.74 grains	at 60° F.
7.98 grains	at 70° F.
10.93 grains	at 80° F.
14.79 grains	at 90° F.

66. Condensation—Dew Point. If air is cooled below the saturation point, some of the water vapor condenses to form water, which may be deposited in several ways, such as mist, fog, clouds, or dew. Because we are most familiar with the deposit that forms on the grass and woodwork, when the air near the ground cools off in the night, the temperature at which any given air becomes saturated on cooling is called the *dew point*. Scarcely ever, however, is the atmosphere saturated with water vapor. In fact, the quantity of water vapor that is in the air varies greatly in different places, and even in the same place at different times. The air must generally be cooled considerably before it reaches the saturation temperature.

67. How the Dew Point May Be Found. Let us take a highly polished narrow metal cup (Fig. 23) half full of water. If we now lower the temperature of this by adding pieces of ice and stirring with a thermometer, a mist will appear on the outside shiny surface, if the quantity of water vapor in the surrounding air is not too small. The temperature at which this mist begins to form is the dew point, as it is an indication of the temperature at which the air next the cold metal becomes saturated. Sometimes it may be necessary to lower the temperature further by using salt and ice if the dew point happens to be very low.

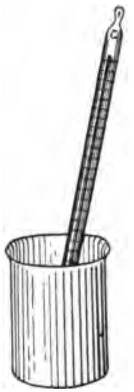
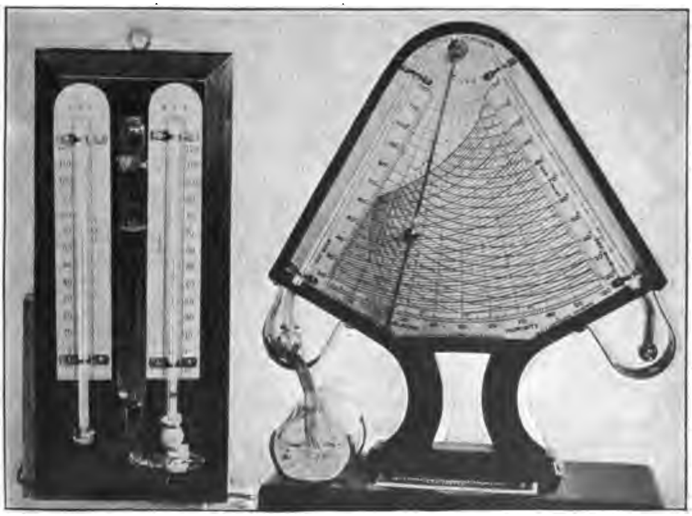


FIG. 23

68. Frost Point. If the quantity of water vapor in the air is very small, there must be a considerable drop in temperature before the vapor condenses. The saturation point may be even below the freezing point of water. In this case it is called the *frost point,* and instead of the water vapor condensing as liquid water, it deposits in the solid form as frost, minute ice particles or snow cloud.

69. Dew, Fog, Mist, Cloud, Rain, Frost, Snow. The difference between dew, fog, mist, cloud, and rain, on the one hand, and frost and snow, on the other hand, lies in the temperature at which the water vapor condensed. If the condensation takes place at a temperature above freezing, any one of the first group *may* form; if below freezing, either one of the second group *may* form. As to whether we get dew, mist, fog, cloud, or rain depends upon where the condensation takes place and in how great an amount. If on the ground or woodwork, etc., it is called *dew;* if in small amount on the dust particles in the air near the ground, *mist;* if in larger amount, *fog;* if high up in the air, *cloud.* In the case of mist, cloud, and fog, the condensed water appears in very minute particles, so light as to float in the air. If now the condensation on the particles in the cloud in-

creases, the cloud becomes darker and the particles so heavy as to fall to the ground as *rain.* If the condensation to form the cloud took place below the freezing point, *snow* results. If the temperature at which condensation takes place is above the freezing point, and it afterward falls below it, the water particles freeze to form *sleet.* *Hail,* generally forming in the summer time, is thought to be a case of clouds forming high in the air and coming in contact with a very cold wind. This wind freezes the water particles and swirls them about with great force, condensation taking place upon them all the time, so that they become quite large before they are heavy enough to drop out of the wind.



(*a*) WET AND DRY BULB THERMOMETER (*b*) HYGRODEIK

FIG. 24

70. Effect of the Heat of Condensation in Preventing Frosts. Inasmuch as water vapor, when it condenses, gives out to the air the heat that the water absorbed when it evaporated, it is evident that the formation of large quantities of dew or other form of condensation sets free a large amount of heat in the air, thus raising its temperature. If, however, the dew point is below the freezing point, there is danger of frost when the temperature of the air is slightly above the freezing point in the evening, as the air near the ground cools off at night. Frost may be predicted when the dew point is known.

The dew point may be calculated by means of a wet bulb thermometer and the table below. A wet bulb thermometer differs from an ordinary dry bulb thermometer in that the bulb is wrapped in a strip of cloth, the lower end of which dips into water (Fig. 24*a*). There is continual evaporation going on from this cloth, the temperature of which is thus lowered. As a result the wet bulb thermometer "reads" lower than the dry one. How much lower it will be depends upon how much water vapor there is in the atmosphere. If we multiply the difference between the readings of the dry and wet bulb thermometers by the number that in the multiplier column of the table is on the same line with the dry thermometer reading in the first column, the product is the number of degrees that the dew point is below the dry bulb temperature.

TABLE FOR DEW POINT DETERMINATION

Dry Bulb Temperature F°	*Multiplier*
32 to 33	3.3
33 " 34	3.0
34 " 35	2.8
35 " 40	2.5
40 " 45	2.2
50 " 55	2.0

71. Relation between Our Feeling of Comfort and the Water Vapor in the Air. The quantity of water vapor in the air has much to do with our feeling of comfort. Our feelings in the matter depend upon the tendency of the perspiration of the body to evaporate and thus cool us off. The human body may be likened to a plant growing in a flower pot. Part of the

water poured on the earth of the plant will pass out through the pores of the pot and there evaporate, making the pot colder than it would otherwise be. The earth around the plant inside the pot, however, is not affected to any considerable degree by this cooling of the outside. In the same way, the human body is covered by a layer of skin, through the pores of which the perspiration passes out to the surface, there to evaporate. The skin, as a result, is much cooler than the body inside; how much cooler depends upon how fast the perspiration evaporates. Now the more water vapor there is in the air the less is the tendency of the perspiration to evaporate. But if that same air is heated, the perspiration will evaporate faster, since warm air can take up more water vapor than can cool air. As a result we may *feel* cooler at the higher temperature. The actual quantity (number of grains) of water vapor in a given volume of air (1 cu. ft.) is called the *humidity* of the air. Now the more nearly saturated any given air is, the less additional water vapor will it take up. Air that may be nearly saturated at one temperature will be much below saturation at a higher temperature. The ratio between the amount of water vapor there is in the air and the amount there would be if the air is saturated is called the *relative humidity*. Raising the temperature of air does not change the humidity, provided there has been no chance for more water vapor to get into the air. Raising the temperature does, however, change the relative humidity, making it lower. For example, if 1 cu. ft. of air at 60° F. contains 2.37 gr. of water vapor, it is about two-fifths saturated; since to be saturated it must contain 5.74 gr. to the cubic foot. Its *humidity* is 2.37 gr. per cubic foot. Its *relative humidity* is $2.74 \div 5.74 = 41.3\%$. This air when heated to 80° F. will still contain 2.37 gr.,[1] but will be about one-fifth saturated; since to be saturated at 80° F. it must

[1] In reality, owing to the expansion of the air, there is a little less than 2.37 gr. to the cu. ft.

contain 10.93 gr. Its humidity is as before, 2.37 gr. per cubic foot, while its relative humidity is 2.37 ÷ 10.93 or 21.6%.

There are two extremes of comfort in regard to water vapor in the air. Air with *too low* relative humidity causes too rapid evaporation of perspiration, with resulting dryness of the skin and the nostrils. Air with *too high* relative humidity causes oppression by too little evaporation, and one feels sticky and damp. The normal condition is 60% relative humidity.

By means of the *hygrodeik* (Fig. 24*b*), the relative humidity and the dew point may be quickly determined by means of a diagram that lies between the two thermometers.

72. **"Drying" Air.** Since raising the temperature lowers the relative humidity, thereby increasing the tendency of water to evaporate into it, warming air is said to "dry" it. What is really meant is that it makes the air *feel* dry; for no water vapor has been driven out of the air by heating, as would have to be the case to *dry* anything. On a "damp" day clothes will not dry so well as on a day when there is less relative humidity. Bringing the clothes into the hot kitchen will, however, hasten the drying on such a day. Mists that are in the air and obscure the sun in the early morning are said to "burn away." The heat from the sun warms the air, thus making it possible for it to take up the mist. Water vapor, both at a low temperature and as steam, is invisible and the sun's rays pass readily through it, while water particles obstruct the rays.

73. **"Too Dry" Air in Many Houses.** This so-called drying of air is a serious trouble in buildings that are heated as well as ventilated by hot air, whether it be by a furnace in a dwelling house or by a fan in large buildings, such as schoolhouses or theaters. In cases where *normal* air is taken in from outside, heated and passed through the rooms where it is to be

breathed, it should be supplied with additional water vapor to bring the relative humidity (lowered by heating) up to standard. Headaches and dry noses result from failure to do this. Thus pans of water are placed in furnaces, and in rooms heated by

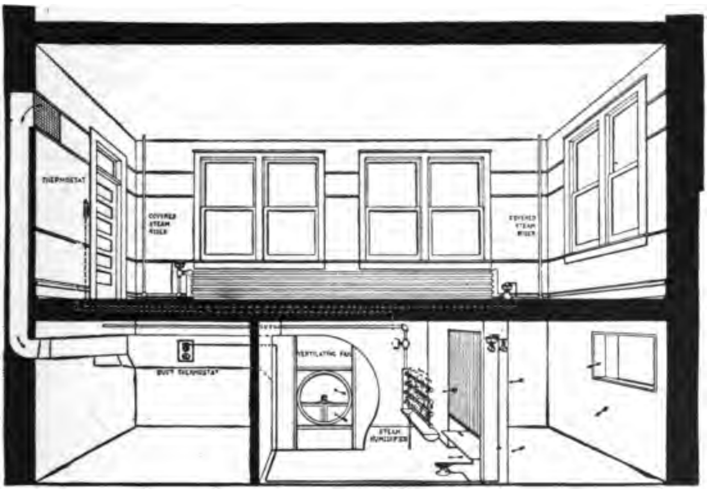


FIG. 25.—VENTILATING SYSTEM THAT SUPPLIES WARM AIR OF CORRECT HUMIDITY

radiators pans of water are placed on the radiators to furnish water vapor to the air. In large buildings, the air, after being heated, should be passed through a spray of water before it is distributed to the rooms (Fig. 25).

QUESTIONS

1. Explain why we "see our breath" on cold days.

2. Why do we not see it on warm days?

3. Explain the mist that forms on our eyeglasses when we come into a warm room from the cold outdoor air.

4. Why does this mist disappear when we have been in the room for some time?

5. What becomes of the "cloud of steam" from the kettle of boiling water?

6. Why does a sudden drop in temperature on a sultry day often cause a fog to form?

7. Explain the moisture that forms on the inside of a bottle that has been rinsed in very hot water, corked, and set aside.

8. Explain how clouds form.

9. Explain why a copious dew prevents a frost.

10. Explain how a day when the temperature is 98° and the relative humidity 60% may feel more comfortable than another day when the temperature is only 80°.

HEAT TRANSFER

74. **Sources of Heat.** As mentioned before, besides the heat generated in the body to keep us alive, heat is needed to carry on the various affairs of life, such as cooking, warming our houses, running engines, etc. The commonest source of heat is the sun, but this has very little direct use other than warming our bodies. For other purposes we resort to the heat obtained from burning such substances as wood, coal, oil, gas, and, in our automobiles and flying machines, gasoline. The treatment of lime with water in the preparation of plaster, and of metal with an acid, and friction between two objects, all produce heat. In olden times heat to start fires was obtained by rotating a stick rapidly on one spot upon another piece of wood. Then the flint and steel of two hundred years ago came into use. The sparks thus obtained are today duplicated by the action of the horses' shoes on the pavements. In those days fire was precious, and

the fire on the hearth was kept going continuously, if possible, after it was once started. Today with our matches, which we set on fire through friction, we little think of the difficulty of former times. Nowadays use is made of electricity as well as of gas as a source both of heat and of light. It furnishes a convenient means of heating, for it is clean, does not use up the oxygen of the air, and does not contaminate the air with unhealthful gases.

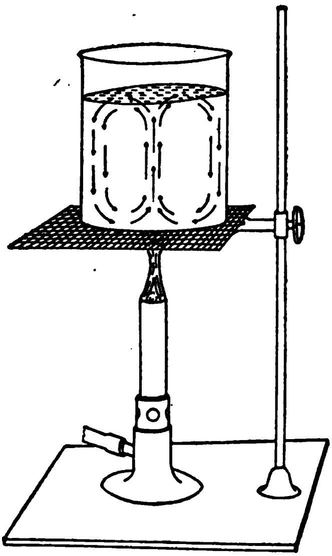


FIG. 26.—CONVECTION CURRENTS IN WATER

75. Convection in Liquids. If we place a beaker of cold water over a small Bunsen flame and look through the water, we notice an irregular wavy condition. Currents of warm water are rising where the flame strikes the glass, and cool water is passing down in other parts of the beaker (Fig. 26).

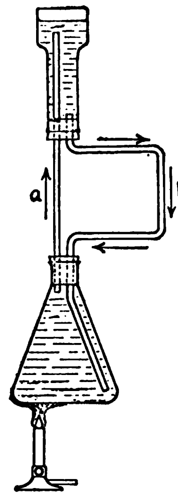


FIG. 27

This action may be more clearly shown by means of the apparatus represented by Figure 27. The heated water, when it expands, does not press down so hard on the bottom of the flask as does the cold water in the tube *b*. The warm water is pushed up the straight tube *a*, over the top of which it collects. At the same time cold water passes down to the bottom of the flask through the bent

tube *b*. If the water in the tube above is colored, the movement of the currents is easily seen. Such transference of heat, always upwards, is known as *convection*, and the currents formed in the water are called *convection currents*. Just such currents go on in the case of the water of a pond cooling at the surface and pushing up the warmer water below (see Section 20).

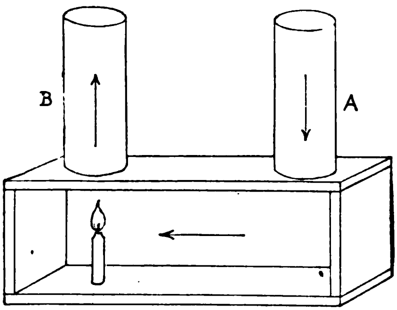


FIG. 28.—CONVECTION IN GASES

This method of transference of heat applies only to fluids (liquids and gases) which are free to move or flow.

76. Convection in Gases. In the case of gases (Fig. 28), a heating of the column of air at the left by the candle flame makes the air column *B* less dense than *A*; therefore column *A* presses down harder than *B* and forces upwards the warm air in *B*. (The front of the box is of glass.) Air will pass up *B* even with the box and *A* removed, as there is cold air on all sides of the candle.

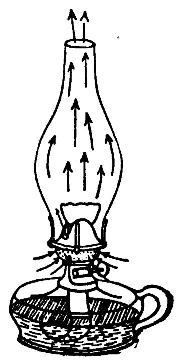


FIG. 29

When we light an ordinary lamp wick (Fig. 29) we get a dim, smoky flame until the chimney is put in place. The light then becomes clear and bright. In this case the air inside the chimney has been heated and forced upwards by the colder air outside the base of the burner. It is this fresh air coming to the flame in greater quantity than before the chimney was put in place that makes the brighter light, because of more perfect combustion.

In the fireplaces of our houses the heat from the fire makes the air in the chimney expand, and thus become less dense. The denser cooler air in the room outside the fireplace pushes the warm air up the chimney, thus creating a draft, constantly renewing the supply of fresh air to the fire, and making it burn better.

FIG. 30

In ventilating a room it is better to open the windows at the top and bottom, so as to allow for an inlet and an outlet (Fig. 30).

77. Circulation of Air in Kitchen Stoves. In the kitchen range there are several regulating dampers. The fire box has an under and an upper damper, to regulate the fire. With the under one opened and the upper one closed, the draft acts *through* the fire to make it burn faster. If the upper *check* damper is opened, the air passes *over* the fire, which thus burns

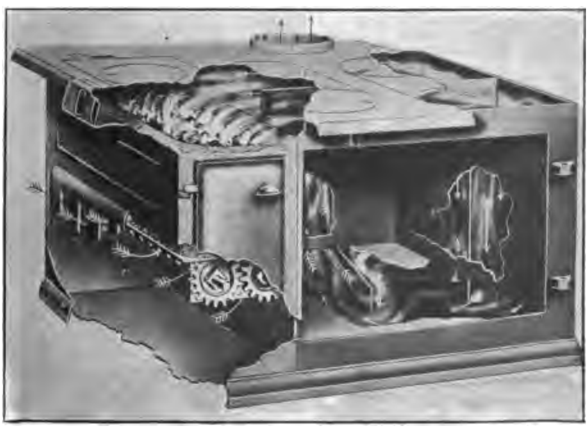


FIG. 31.—PATH OF THE HOT AIR AROUND THE OVEN

with less violence. There is also a smoke pipe damper, which, when shut, serves as an additional check on the draft. Finally, there is an oven damper to direct the hot gases around the oven (Fig. 31), instead of allowing them to go straight up the chimney from the fire box. When this damper is acting, the top, bottom, sides, and back of the oven are heated.

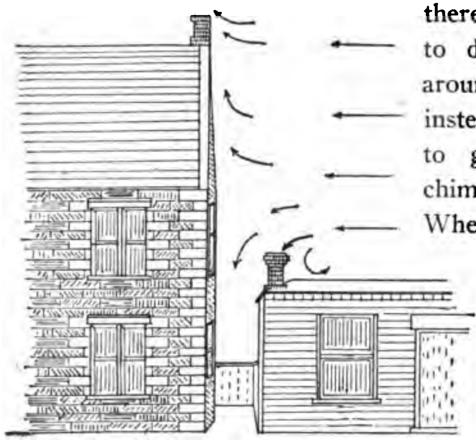


FIG. 32.—DOWN DRAFT IN A CHIMNEY

78. Smoky Stoves and Fireplaces. Sometimes when a fire is started in a fireplace or a stove, the air in the chimney is cooler than in the room, with the result that the chimney "smokes." To remedy this condition, the air in the chimney may be

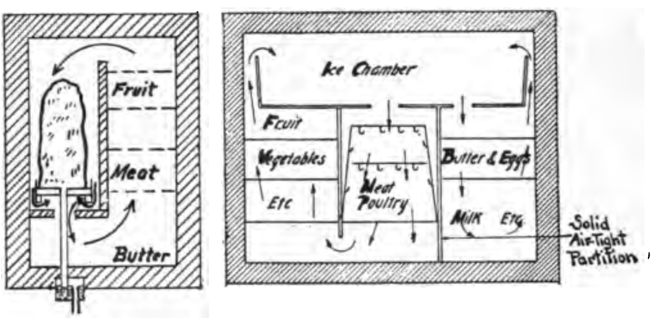


FIG. 33.—REFRIGERATORS IN SECTION

warmed by holding a burning paper a little way up the chimney flue. A smoky fireplace or stove may be due to the above cause or to any of the following:

The chimney may not be high enough.

The flue may be too large, so that the air in it does not get heated fast enough.

There may not be sufficient chance for air to get into the room and up the chimney.

There may be two chimneys of different heights in adjoining rooms (compare Fig. 28), so that when a fire is burning at the bottom of one it may be difficult to start a fire in the other, which has been acting as a course for the cold air downwards.

The wind, owing to walls or roofs of houses near by, may blow down the chimney (Fig. 32).

79. **Refrigerator.** In the refrigerator (Fig. 33) the ice is always placed near the top, so that the cold air in falling will force the warm air below up to the top, thereby bringing the cold air in contact with the food. The warm air, when cooled by the ice above, in turn falls.

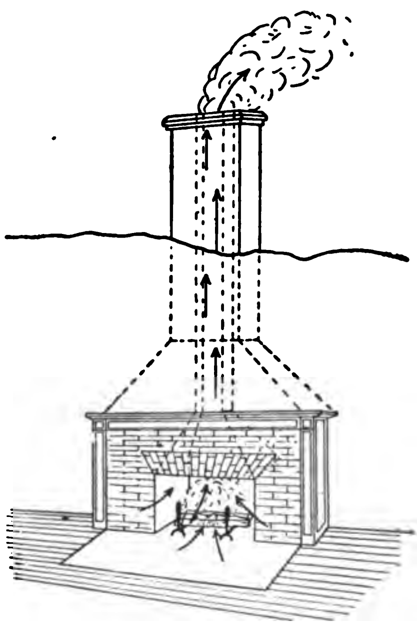


FIG. 34.—THE FIREPLACE HELPS TO VENTILATE THE ROOM

HEATING SYSTEMS

80. **Development of Our Modern Heating Systems.** Before coal came into general use, wood fires were the means of heating our houses, and fireplaces (Fig. 34) were built in nearly every room. Then came the air-tight wood stoves that warmed the rooms more effectively, as less heat was lost up the chimney. With the discovery of coal as a fuel, there resulted a means of keeping the fires

more easily and of maintaining a more uniform temperature in houses.

The dirt from the ashes, the inconvenience of carrying fuel to each room, and the keeping up of several fires in the different coal stoves, brought about our modern methods of heating. Nowadays, the fires are combined into one central heater in the

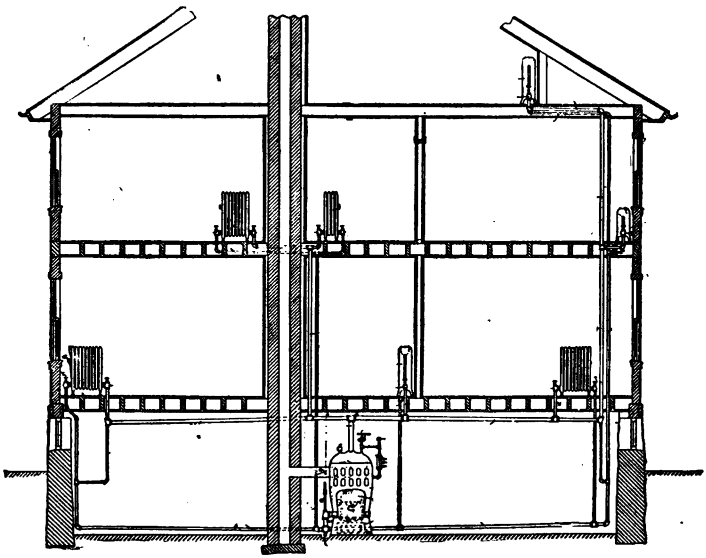


FIG. 35.—STEAM HEATING SYSTEM

cellar. The heat from this is transferred, as needed, to the different rooms of the house. The three methods by which this transference is carried out are by the use of hot air, of hot water, and of steam. The last of these, the steam heating system (Fig. 35), takes advantage of the fact that when water turns to steam it expands. The resulting steam is forced, by the steam forming behind it, through pipes to radiators in the

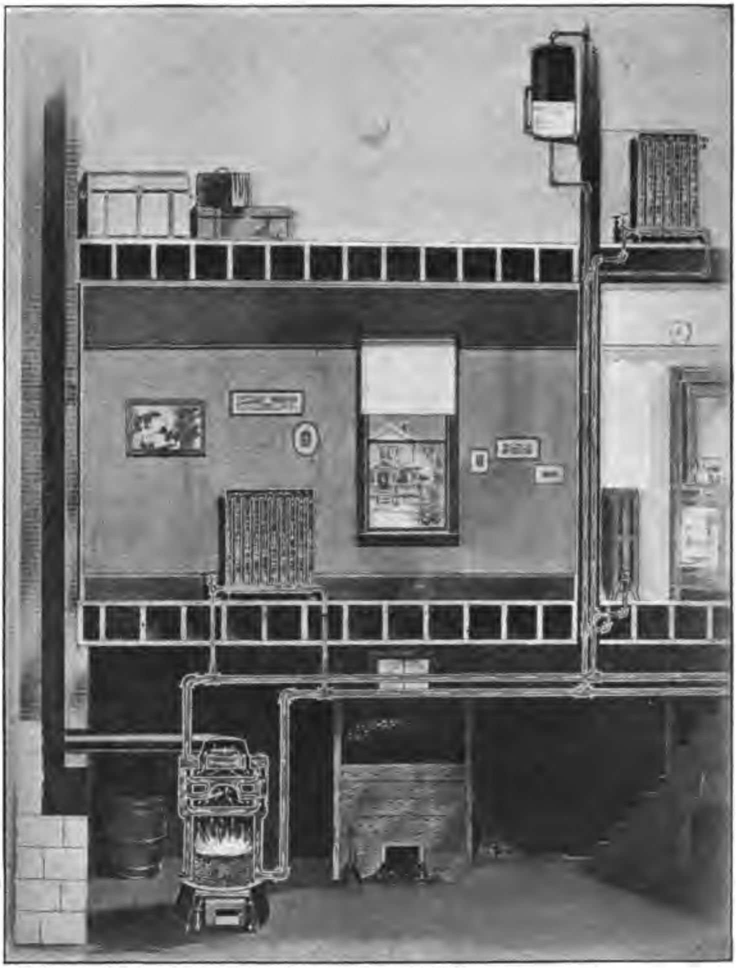


FIG. 36.—HOT WATER HEATING SYSTEM

different rooms, where it condenses. In condensing it gives off the heat of vaporization which was put into the water to convert it into steam. In so doing, the steam turns back to water, which then flows down to the heater, where the water is again heated and turned to steam.

81. Hot Water Heating System. In Figure 36 is shown the use of convection in the heating of a house by hot water. Inasmuch as water tends to expand when heated, and, if not allowed to do so, exerts enormous pressure, an expansion tank in the upper part of the house is necessary to provide for this expansion.

The cold water, entering the heater through a pipe at the bottom, pushes the hot water up into the pipe at the top of the heater, through which it passes to the radiators, there to cool, give off its heat to the room, and then to return to the heater through the cold water pipe, to be heated again.

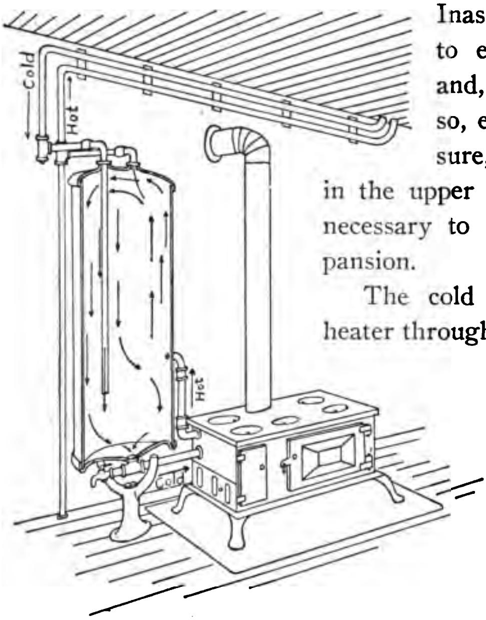


FIG. 37.—KITCHEN HOT WATER TANK

82. Hot Water Supply System. The same system applies to the heating of water in the kitchen boiler, to be used for washing purposes (Fig. 37). As in the heating system, there is usually a tank higher than the boiler, to allow for expansion.

This tank also supplies more water to the boiler, when the hot water is drawn off through the faucets. It is kept filled automatically with cold water from the street main. The pipe from this tank passes down through the top of the boiler, ending near the bottom. Cold water passes from the boiler through the

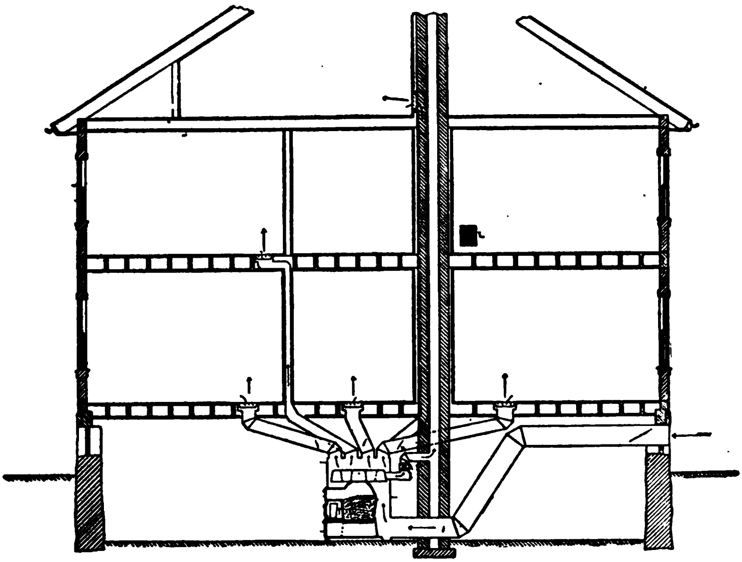


FIG. 38.—HOT AIR HEATING SYSTEM

lower pipe to the water-back in the stove, where, upon being heated, it is pushed up and back to the boiler, which it enters about a third way up the side. On entering the boiler, the hot water mixes with the cooler water. The warmer water is always at the top of the boiler.

83. Hot Air Heating System. In heating a house by hot air (Fig. 38), there is a large stove called a *fire box,* which is surrounded by a brick or galvanized iron *jacket* forming a

furnace (Fig. 39). This jacket is connected at the bottom with the outdoor air through a passage called the *cold air inlet.* From the top of the furnace jacket pipes pass to the different rooms. The air between the jacket and the fire box becomes heated and is forced to the different rooms by the greater pressure of the cold outside air.

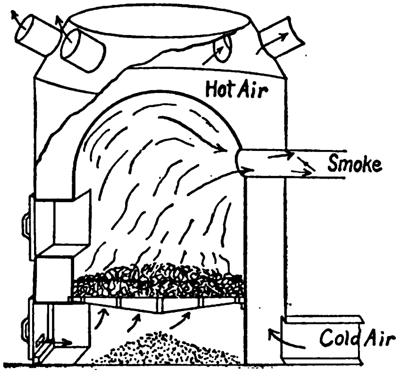


FIG. 39.—FURNACE

84. Comparison of (I) Steam, (II) Hot Water, and (III) Hot Air Systems. The heat obtained from the three methods of heating is respectively from (I) the condensation of the steam, (II) the cooling of the water, (III) the cooling of the air. The steam thus provides a more intense heat, but it takes much longer to get heat in a steam heating system, as the water in the boiler must all be boiling before any steam will come to the room. In hot water and hot air, convection takes place as soon as the water or the air becomes heated, and we thus get some warmth into the rooms very quickly. Furthermore, from these last two systems on mild days we can get enough heat to take the chill out of the air with a low fire, which would not be hot enough to produce steam in any quantity. Finally, hot air furnishes fresh air as well as heat, thereby ventilating a room somewhat; while with steam or hot water, ventilation must be secured through open windows or doors. In all cases, the heated air should be brought to the right humidity by the addition of water vapor. In the hot air system this is

partially secured by means of the water pan in the furnace; in steam and hot water systems by pans of water placed upon or under the radiators.

85. Heating of Schoolrooms and Public Buildings. The supply of fresh air furnished to rooms by natural ventilation is not sufficient for breathing purposes when there are many persons occupying the same room. In such cases an *indirect* system of ventilating and heating combined is employed. The commonest of these is the fan system (Fig. 25), in which fresh air is pumped in from outside by means of a centrifugal fan or blower. This air is forced through radiators in the basement and then through ducts to the different rooms. The impure air breathed out by the persons is forced out through flues leading to the roof. The best places for inlet and outlet are shown by Figure 40. When the inlet is above the outlet on the same side of the room, there is a thorough circulation of the fresh air to all parts of the room.

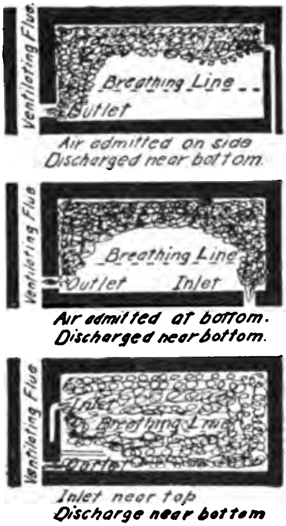


FIG. 40

QUESTIONS

1. Explain the draft in a chimney.

2. Explain why there is sometimes a down draft in a chimney. When is this likely to happen?

3. Why do tall chimneys have better drafts?

4. Why is a room with a fireplace better ventilated than one without?

5. Is the smoke pulled or pushed up the chimney? Explain.

6. Explain why it is not practicable to place the ice in the lower part of the refrigerator.

7. Explain why it is difficult sometimes in a hot air heating system to get the hot air to go to some particular room.

perature, as indicated by the failure of the air in the bulb to expand. The colored liquid in the stem does not fall.

88. Uses of Poor Conductors—Insulators. Because of the great conductivity of metal, substances which are poor con-

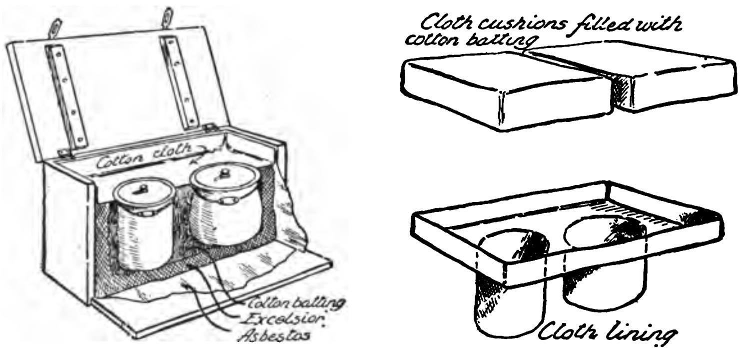


FIG. 43.—FIRELESS COOKER

ductors, called heat *insulators,* are always placed between hot objects and anything that would be injured by the heat from them. As examples, sadirons have wooden handles, flatirons are held with cloth pads, mats are placed on the dining room table for hot dishes to rest upon, the handles of silver teapots are fastened to the body of the pot with glass or ivory discs, and chafing dish handles are made of wood or horn. The fact that asbestos is an insulator makes it of great use for covering steam pipes to keep them from cooling as steam passes through them to the radiators in the different rooms. The walls of refrigerators (Fig. 42) are made up of successive layers of insulating material. Storm windows are put on in winter to furnish a layer of confined air between the warm room and the outside cold air. Our fireless cookers utilize the poor conductivity of air in that the hot food is shut up in air-tight compartments

(Fig. 43). The heat put into the food cannot easily escape, so the cooking goes on, aided sometimes by the heat from hot soapstone slabs put above and below the vessel containing the food. The modern vacuum bottle (Fig. 44) that keeps liquids either hot or cold, as may be desired, is based on the fact that the space between the inner and outer bottle has no air in it. A vacuum, which is a space unoccupied by any solid, liquid or gas, is even better than air as an insulator.

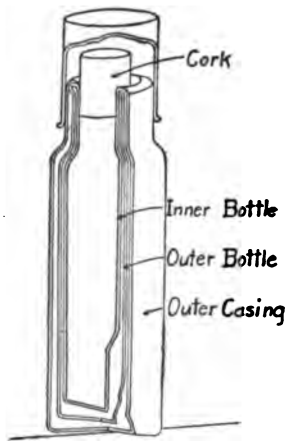


FIG. 44.—VACUUM BOTTLE

89. Conductivity as Regards Our Temperature Sense. That different substances have different conductivities is shown by the fact that in a room where all the articles have the same temperature some feel cooler than others. For instance, the metal work feels cool, the wood not so cool, and the cloth warm. The explanation of this is that they are all *cooler* than the body. Heat therefore passes from the body to each one. In the case of the metal (good conductor) this heat spreads out through it, thereby allowing the heat to leave the hand more easily than in the case of the wood or the cloth (poor conductors), where only the spot touched is heated. If, on the other hand, the room is very hot (above 100° F.), the iron will be found to feel hottest and the cloth coolest. Here all the objects are *warmer* than the body, and when they are touched in one spot, the heat from the other parts of good conductors such as the metals is easily conducted to the part touched. The result is that in the case of metals heat from a considerable area goes into the hand, while from the poor conductors the

heat enters the hand only from the spot touched. The two sensations of heat resulting will be quite different on this account.

Water may be boiled in a paper dish held over a low bunsen flame without the paper burning. Here we have a most striking example of the fact that water cannot be heated in an open dish much above 100° C. The paper being thin conducts the heat readily through to the water. The paper cannot become hotter than the water inside, and as the kindling temperature of paper is much above 100° C., it is impossible to set it on fire as long as there is water over the bottom of the dish. This cannot be done with a cardboard box, as heat is not conducted readily enough through the thick cardboard.

90. Radiation. We have thus far learned that heat may be transferred by convection, in which the heat is carried upwards; and by conduction, in which the heat is transmitted from the warmer to the colder part of an object. Also we have learned that air is a very poor conductor of heat. Neither of these methods then will explain how our hand feels hot if held beneath a hot object. The manner in which heat shows its presence in this case is known as *radiation*. Since it is neither conduction nor convection, this radiation must take place in a medium different from that in the other two cases. We get the benefit of the heat of the sun, as we all realize every day of our lives. Now the sun is some 93,000,000 miles away, and we know from the experience of men who have gone high up in balloons that the air becomes rarer and rarer the higher they go. Depending on this, it is calculated that our atmosphere extends about 50 miles above the earth. From the upper limit of the atmosphere to the sun there is said to be a vacuum. Therefore a new medium has to be considered through which the sun's heat can travel. To this is given the name of *radiant ether,* or more

simply, *ether*. It is called radiant because it is the means of transmitting the so-called *radiant energy,* a name given to the energy of heat and light. This ether is supposed to be everywhere, whether or not air is present.

91. Molecular Composition of Substances and Molecular Theory of Heat. For a better understanding of this radiant energy, which we must now consider, an understanding of what goes to make up substances and what is happening to them is necessary. According to the present accepted theory, substances are made up of *molecules,* which are very small particles, so small that they cannot be seen with the most powerful microscope known. Between these molecules are spaces. There are many kinds of molecules, but those of any given kind of substance are all alike; and it is by the combined action of all the molecules of the same kind that we are able to say what each molecule is doing. The molecules are continually moving back and forth in a vibratory manner, hitting one another and also hitting molecules of another sort at the surface of the object. There is a certain amount of friction between these molecules as they rub or hit against one another, and this results in the internal heat of the object. The faster the molecules vibrate the greater becomes the friction and the higher the temperature of the substance. Heat may thus be said to be due to the energy of vibration of the molecules.

92. Waves. If we throw a stone or other object upon the quiet surface of a pool or pond, ripples or waves form on the water and spread out in all directions on the surface (Fig. 45, frontispiece). These form a series of concentric circles which become larger and larger until they finally strike the shore with more or less force. Any disturbance of still water produces such an effect. Now the ether is just as susceptible as is

water of having waves set up in it when it is disturbed. The main difference is that it requires a different sort of disturbance. Furthermore, when once started, the waves pass in *every* direction from the point of disturbance outwards, not in concentric circles, but in concentric hollow spheres. *Molecular vibration* is the disturbance that starts these ether waves, which depend for their frequency on the rapidity of the molecular vibration. The more rapidly the waves form, the shorter they are; and *vice versa,* long waves are due to a disturbance from a less rapid molecular vibration.

93. **Heat and Light Both Produced by Molecular Vibration, Differing in Degree.** If we hold a small piece of iron in a hot flame, at first there is no perceptible change in appearance, though the molecules are being set in more rapid vibration. We are aware, however, that the iron is becoming hotter by the fact that it feels warmer if held a short distance from the face. On further heating, a condition is reached at which the iron begins to take on a dull red color, followed by a bright red, and finally reaches a white heat. Another of our senses, sight, has come into use, and we say the iron gives off both heat and light. Both these conditions have been produced by putting heat into the iron, thereby causing an increased vibration of the molecules. Furthermore, the effect of this increased vibration is produced upon the skin and eyes nearly equally in every direction from the hot object. The action has taken place through the ether and the cause has been radiant energy. Thus heat and light are closely connected, differing largely in degree of vibration of the molecules and in the effect of the waves upon our senses.

Naturally the waves set up in the ether by the slower vibrations are longer, and we say that heat waves are the longer ether

waves; while the waves produced by the faster vibrations are short, thus giving us short ether waves, or light waves. Both are waves originating in radiant energy.

Just as our bodies react differently to the two kinds of waves (long and short), so do other substances react differently to them, and we find that light waves will produce many effects other than those produced by heat waves.

Review Questions on Heat

1. Explain why two pieces of ice stick after they have been squeezed together.

2. Why does heat on one side curl up paper?

3. What connection is there between "sunstroke" and a dry skin?

4. Why is steam as a source of heat more effective in heating a room than is hot water?

5. Why do animals have a thicker coat of fur in winter?

6. Why does bread "rise" when it is being baked?

7. Why do automobilists use glycerin or alcohol in the radiators of the engine in winter?

8. Why is zinc placed under stoves, and on woodwork near hot furnace pipes?

9. Why are heaters always in the cellar?

10. Explain how the automatic fire sprinkler works.

11. Why do electric fans prevent frost from forming on windows in winter?

12. Why is the water from the hot water faucet cold at first?

13. Explain why a wet flower pot is cooler than a dry one.

14. Explain the bubbles that form on the inside of a tumbler of cold water after it has been standing for some time.

15. Wherein is cooking by means of a fireless cooker an advantage?

16. Why are brick houses cooler than wooden ones in summer?

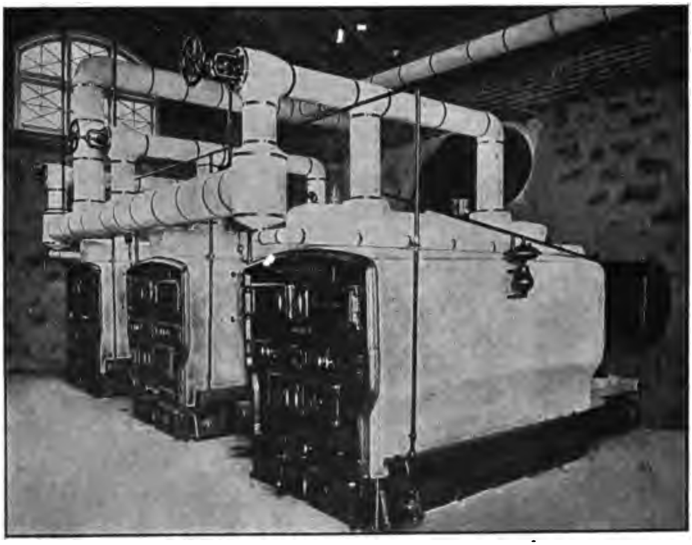


FIG. 46

17. Why does bread curl on the side toward the heat when it is being toasted?

18. Explain the cook stove heat indicator.

19. Explain the "sweating" of cold water pitchers and cold water pipes in summer.

20. Why are the pipes in the cellar sometimes covered with asbestos, felt, or magnesia (Fig. 46)?

21. Explain why a glass stopper that sticks may be loosened by quickly heating the neck of the bottle in a candle flame.

22. Explain the wind that generally forms when a conflagration starts in still air. In what direction does it blow?

23. Why are cloths placed over an ice cream freezer after the freezing is complete?

24. Why is it unwise to draw off considerable hot water from the boiler after the stove fire has been "banked" for the night?

25. Why does burning paper held up a smoky chimney often remedy the trouble?

26. Explain how the teapot is kept warm by the old-fashioned "tea cozy." This consists of a large padded cap that fits over the teapot.

27. Why does a hot tumbler crack when put into cold water, and why does a cold tumbler crack when put into hot water?

28. Why is a metal pipe sometimes built into the top of a chimney?

29. Explain why a wet towel on the line is colder than a dry one.

30. Why do deep ponds generally take longer to freeze than do shallow ones?

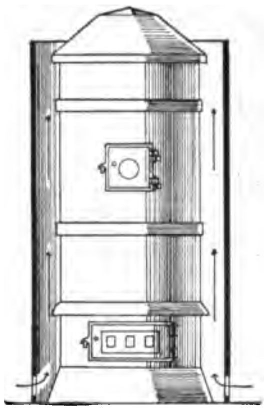


FIG. 47.—JACKETED STOVE

31. Explain how frost forms on the windows and not in the rooms.

32. Why does an iron jacket placed three-quarters around a parlor stove (Fig. 47) make the stove heat the room better?

33. Where in the refrigerator is the best place to put odorous substances? Explain.

34. Why do birds ruffle up their feathers on cold days in winter?

35. Why is a cotton puff generally preferred to a woolen blanket?

36. Why is an ice cream freezer with a metal outer pail not so good as one with a wooden outer pail?

37. Why are thin glass tumblers less likely to crack than are thick ones when heated or cooled suddenly?

38. How does glycerin on windows tend to prevent them from becoming coated with frost?

39. What is generally the cause of a "smoky" stove?

40. Why are the walls of houses sometimes built of hollow bricks?

41. On the basis of the accepted theory of the composition of substances, explain why objects expand when heated and contract when cooled.

42. Why should chimneys built in the central part of the house "draw" better than those built on the outside?

43. At which time of the year, winter or summer, can a room be aired more quickly with the windows open? Explain.

CHAPTER III

LIGHT

Sources of Light Waves.
Intensity of Light.
Effects Produced by Objects upon Light Waves.
- Shadows.
- Phases of the Moon.
- Eclipses.

Reflection of Light Waves.
- Law of Reflection.
- Mirrors.
- Images Formed by Mirrors.

Refraction of Light Waves.
- Cause and Explanation.
- Total Internal Reflection.
- Prism Effect.
- Lenses.

Optical Instruments.
- Camera. Photography.
- Human Eye. Defects and Correction.
- Projection Lantern.
- Telescopes.
- Microscope.
- Opera Glass.

Dispersion of Light.
- Color. Color Sensation.
- Absorption and Reflection of Color Waves.
- Colors of Objects.
- Mixing of Colors and Pigments.

Printing in Color.
Rainbow.
Radiant Energy Continued.

94. Sources of Light. If we turn our attention to the various sources of light, we find that they are the same as those from which we derive heat. The sun is our natural source; artificially we have the burning of wax, oil, gas, and the effect produced by the electric current upon the carbon and tungsten filaments in the incandescent lamps, and upon the carbon rods in the arc lamps. Such sources of light are called *luminous* objects. Objects which do not emit light are called *non-luminous;* but upon receiving light waves from luminous objects these become *illuminated.*

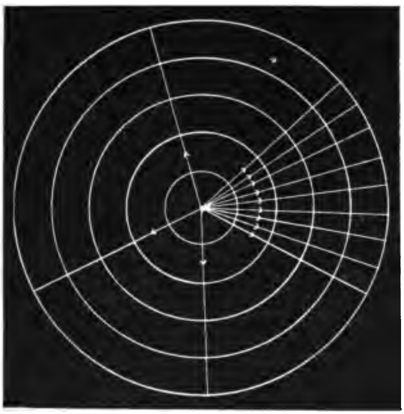


FIG. 48.—LIGHT WAVES SPREAD IN ALL DIRECTIONS

95. Direction in Which Light Waves Move. Light waves are supposed to move outwards in every direction from their source. As the light waves move farther from their origin they continually spread out through a larger space (Fig. 48). That they pass in a straight line is apparent from the fact that if we hold between the light and our eye some object through which light waves cannot pass, we can no longer see the light. We all know that it is impossible to see things around a corner without the aid of a reflector. The direction in which the wave may be

moving at any particular point is called a *ray*, and for convenience the term ray of light is frequently used instead of wave of light, which is what is really referred to. Thus we speak of the sun's rays falling upon objects about us.

96. Opaque, Translucent, and Transparent Objects. There are some things through which light waves will not pass at all. Metals and wood in thick layers are examples of such objects, which are called *opaque*. Some substances allow light waves to pass through and illuminate objects on the other side, but the objects cannot be seen through them. To this class belong paper, ground glass, milk; all of which are called *translucent*. Finally, through such substances as clear glass, water, air, objects on the other side can be readily seen. This class of substances is called *transparent*.

EFFECTS PRODUCED BY OBJECTS UPON LIGHT WAVES

97. Whenever light waves encounter any medium other than ether, any one of three things can happen to them: they may be *transmitted*, as by glass; *reflected*, as from mirrors; *absorbed*, as by dark walls in rooms. Generally two or more of these effects take place together. We know that sunlight falling upon a glass window lights up the room within; but at the same time it obscures the interior of the room from a person outside. The reflected glare dazzles his eyes. It is because of the reflected light that one cannot see out of the window at night when there is a light in the room. That the color of the wall paper makes considerable difference as to how brilliantly a room is lighted by a lamp is well known (Fig. 49).

98. Intensity of Light. As we move away from a light

source, such as a gas flame, the brightness of illumination on a book decreases rapidly. This is because a smaller portion of the light waves is falling upon the book. The intensity of light depends upon what part of the waves is intercepted. Let us consider only that portion of the waves from the source O (Fig. 50) that is included within the four rays Oa, Ob, Oc, and Od. If a book is placed at *A* so that its four corners are just included within the rays, then all the light rays fall upon the book. If, however, we place the book at *B*, twice as far away, only one-fourth of the light falls

FIG. 49.—THE TWO ROOMS RECEIVE THE SAME AMOUNT OF OVERHEAD LIGHT. THE TABLES ARE UNEQUALLY ILLUMINATED

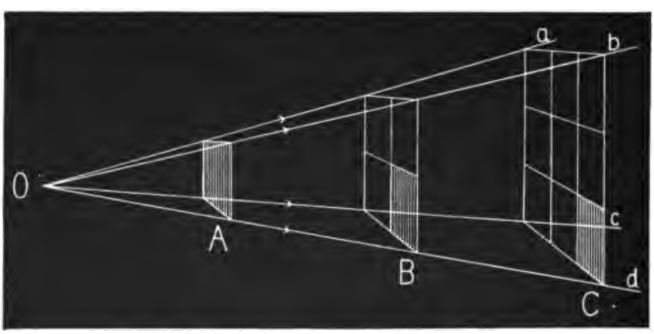


FIG. 50

upon the book. At *C*, three times as far away, only one-ninth of the light falls upon it.[1] From the above result we say that the intensity of light diminishes as the square of the distance from the source. Many people do not realize this, and attempt to read with the light too far away. Much eyestrain results from this abuse of the eyes.

We speak of various sources of light as being of so many candle power. The ordinary fishtail gas flame (Fig. 51) is rated at 22 candle power; the Welsbach burner (Fig. 52) at 60; the incandescent electric light at 8, 16, 32, etc., candlepower. This means that at equal distances from any object they will illuminate the object with that many times as much light intensity as will one standard candle. These candle powers are determined by finding how far away the given lights must be placed to illuminate a screen with the same intensity as does a candle at unit distance (for instance, 1 ft.). If the given lamp must be placed 3 ft. away, then it is of 9 candle power, since, if it is moved up to the same distance from the screen as is the candle, it will be one-third as far away as before, and will illuminate the screen nine times as much. Thus the intensity of a light is determined by the square of its relative distance from a screen

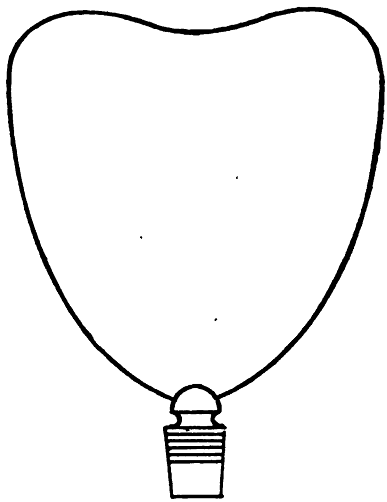


FIG. 51.—FISHTAIL BURNER

[1] The rays have diverged, not only horizontally but vertically as well.

which it illuminates with the same intensity as does some standard light. If two lights, one of 16 candle power and the other unknown, illuminate the screen equally when the unknown one is 3 ft. away and the 16 candle power one is 2 ft. away, then the unknown being $\frac{3}{2}$ as far away is $\frac{9}{4}$ as powerful as the other. Its candle power is $\frac{9}{4} \times 16$, which is 36.

FIG. 52.—WELSBACH LAMP

WELSBACH JUNIOR LAMP

PROBLEMS

1. An ordinary single flat wick kerosene lamp and a candle illuminate a card equally when they are respectively 6 ft. and 2 ft. from the card. What is the candle power of the lamp?

2. A round wick kerosene lamp must be placed 12 ft. away from the screen to produce the same effect as a candle 2 ft. away. What is the candle power of this lamp?

3. What is the candle power of an ordinary fishtail gas flame when the distances of candle and gas flame to produce equal illumination are respectively 9.5 ft. and 2 ft.?

4. Find the candle power of the three Welsbach lights when the distances for equal illumination are as indicated:

Welsbach upright	8 ft.	candle 1	ft.
Welsbach inverted	12 ft.	candle 1.5	ft.
Welsbach Junior	13 ft.	candle 2	ft.

5. If kerosene costs 10 cents a gallon, which is the cheaper lamp to burn for every candle power obtained, the single flat wick or the round wick type; if the single burns 1 pint in 16 hours and the round wick burns 1 pint in 4 hours?

6. The fishtail burner uses 6 cu. ft. per hour; the Welsbach upright 3.5 cu. ft.; the Welsbach inverted 4 cu. ft.; the Welsbach Junior 2 cu. ft. Calculate the cost of running each light for an hour if gas costs 80 cents per thousand cubic feet.

7. Calculate how much each of the above lights costs per candle power, if burned for an hour. Which light is the most economical of the gas and oil lights?

8. State which sources of light seem the best to you, giving your reasons, and also stating the objection to the others.

9. Why can we not see around corners?

10. Name two substances other than those mentioned in the book which are (1) opaque, (2) translucent, (3) transparent.

99. Velocity of Light Waves. The rate at which light waves travel through ether is very great, namely, 186,000 miles per second. They would thus go seven times around the earth in one second. As compared with sound waves, which we shall later learn are waves in the air or in some other material medium, the time light waves take to travel is insignificant. We see the steam from a blowing whistle almost the instant it occurs. We do not hear it for some time. Sound waves move about 1,000 ft. per second. Thus it takes about 5 seconds for sound

waves to travel one mile. Hence the saying that if we divide by five the time in seconds that elapses between seeing the lightning flash and hearing the thunder, we can tell how many miles away the lightning is.

100. Shadows. As we walk along when the sun is shining, we notice what we call our shadow upon the sidewalk. This shadow is due to the fact that the light waves have been stopped by the body, which is opaque. Now not only have they been cut off from the dark part on the ground, but from all the space included between it and our body. This space is called the real *shadow* of the body. We cannot see that the light waves are absent from this space unless we hold some object there. The formation of shadows necessitates our having an unobstructed space between us and the light when we read at night. That we can see the object at all when it is in shadow we shall later find is due to light waves reflected from other objects near at hand.

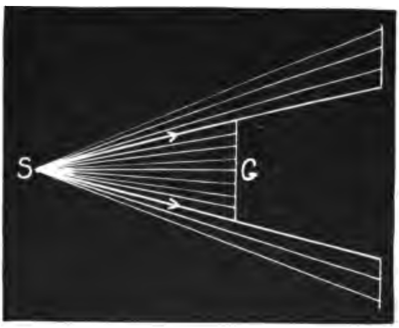


FIG. 53.—SIMPLE SHADOW

Shadows form whenever light waves strike opaque objects. Figure 53 represents the simplest form of shadow. If the source of light *S* is very small, we may assume that light waves are diverging from it in every direction. Those which strike the card *G* do not pass through it, and the space inclosed between the rays that pass by the edges is in darkness. A dark spot of the same shape but larger than the card will be outlined on the wall. If the source of the light is a candle flame,

there is some distance from the top to the bottom of the flame. We may look upon the flame as made up of many tiny points of light from each of which rays diverge (Fig. 54).

FIG. 54

Taking the top particle (Fig. 55*a*), a shadow represented in section by *A B C D* will form, and if it were the only source, *C D* would represent total darkness on the wall. Light waves which pass from the bottom particle alone would give a similar dark area, *E F* (Fig. 55*b*).

If now we consider both top and bottom part as giving light waves together, we shall get a condition represented by Figure 55*c*, in which the portion *A B F C* is getting no light waves, while *A C E* and *B F D* are getting waves from part but not from all of the flame. As a result we have a dark spot bordered by a fringe that shades off from total darkness to complete illumination. We call the central dark portion the *umbra* and the shaded portion the *penumbra*. For this reason shadows formed when large lights are used are not sharp on the edges. If the source of light is much larger than the opaque object, the space represented by *A B F C* will be smaller at *C F* than at *A B*; and if the wall were not there, there would be a limit to the

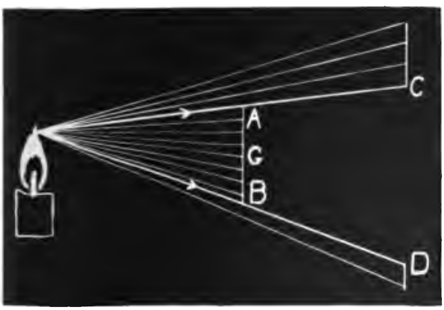


FIG. 55*a*

umbra, which would be conical (Fig. 56). Such a situation results in the case of the shadows cast by the earth and the moon, since the sun is larger than either.

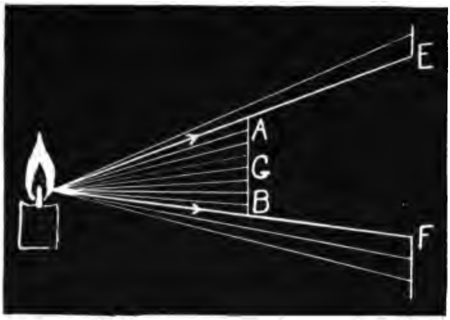


FIG. 55*b*

101. Phases of the Moon. The formation of shadows plays a conspicuous part in our lives in the matter of eclipses, both of the sun and of the moon. To understand this we must bear in mind that the earth is moving in nearly a circle around the sun, taking a year to do it. At the same time the earth rotates on its axis, giving us day and night. Around the earth the moon moves once a month. All the time the half of the earth or of the moon on the side toward the sun is illuminated. This results in day on the earth. How the moon will look to us depends on where it is in relation to the earth (see Fig. 57). As a result we get the *phases* of the moon during the different parts of the month.

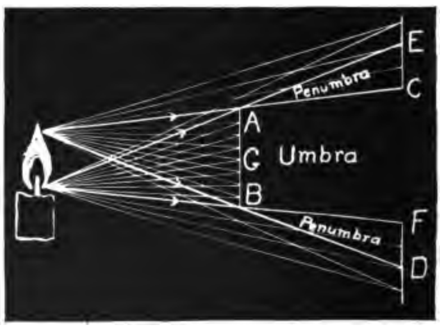


FIG. 55*c*

Note.—In this Figure 57 the inner circle of figures represents the moon as light waves from the sun actually fall upon it. The outer circle of figures represents the moon as it appears

to a person standing at a place where the sun is *setting* in the case of the first quarter, and at a place where it is *rising* in the case of the last quarter.

102. Eclipses. While it is true that during a month the

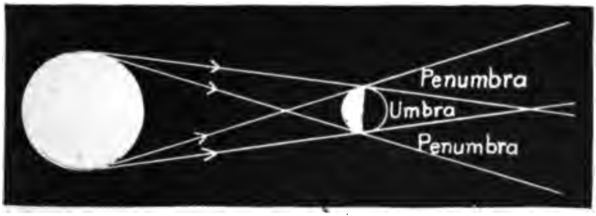


FIG. 56

moon is alternately on the side of the earth nearer the sun and farther from the sun respectively, it does not follow that the moon's shadow will fall on the earth nor that the earth's shadow

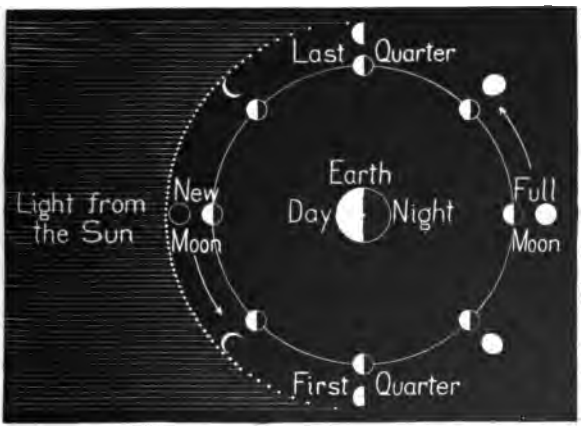


FIG. 57.—PHASES OF THE MOON

will fall on the moon *every* month. This is because the moon does not move around the earth in the same plane as does the

earth around the sun, and consequently, under certain conditions only, will the line passing through the three be straight (Fig. 58). When it is so, however, we have an eclipse (*a*) of the moon, when the moon is in the earth's shadow, and (*b*) of the

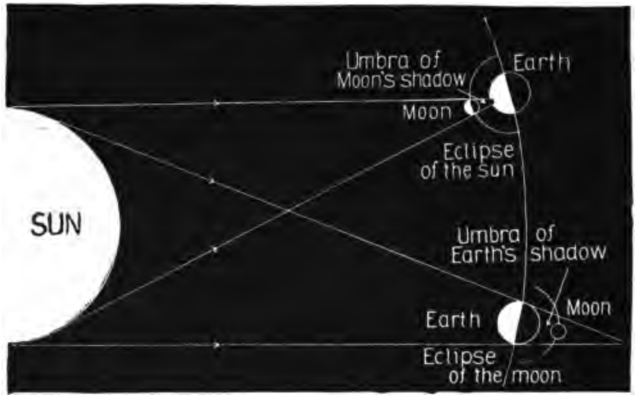


FIG. 58.—ECLIPSE OF THE SUN AND OF THE MOON

sun, when some part of the earth lies in the moon's shadow. Both kinds of eclipses occur near March and September. When we have an eclipse of the moon, the moon, being much smaller than the earth, may be completely cut off from the direct rays of the sun. In the case of an eclipse of the sun, however, only a portion of the earth's surface can be in the moon's shadow at one time.

QUESTIONS

1. What is the difference between a self-luminous and non-luminous object? Classify the following as luminous and non-luminous: moon, sun, lighted candle flame, coal in the bin, a human being, earth, stars.

2. Since all three effects, transmission, reflection, and

absorption, take place more or less when light waves meet a different medium, explain why we call substances opaque, transparent, or reflecting.

3. What is meant by a ray of light?

4. What is the purpose of putting arrowheads on lines that represent rays of light in drawings?

5. Will a piece of glass cast a shadow? Explain.

6. Why is the outline of the shadow of a tree shorter at some times than at others?

7. To what portion of the people on the earth is an eclipse of the moon visible?

8. Why do we see the moon at night only during one-half the month?

9. Explain why eclipses of the moon are commoner than those of the sun in any particular locality.

10. Should the horns of the new moon point up or down? Explain.

11. Why is our shadow behind us as we walk toward a light and in front of us as we walk away?

12. Why does our shadow grow smaller as we move away from the light?

13. Why should persons write with the light coming from the left?

14. How are silhouettes made?

REFLECTION

103. Reflection of Light Waves. If we hold a mirror either of silvered glass or polished metal in the sunlight that shines into a room, we find that the light disappears from the spot where the mirror's shadow falls and appears at another spot

which is now illuminated more brightly than before. The rest of the room remains practically unchanged. If, however, we use a piece of white rough paper, instead of a mirror, we find that the room becomes slightly brighter. In both cases the light waves have been affected, though differently. In the first case, by turning the mirror we can shift the point of illumination. We cannot do so with the paper. There has been a regular effect produced by the mirror. The rays have not been scattered, since

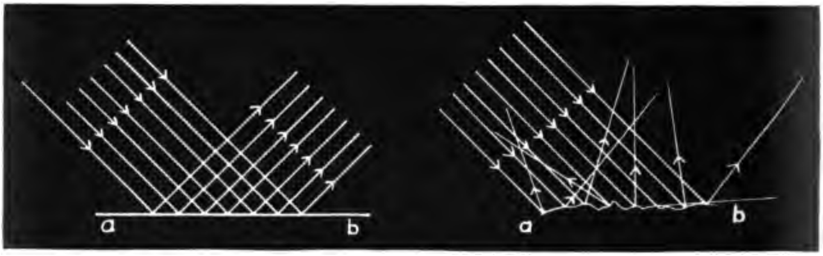


FIG. 59*a*.—REGULAR REFLECTION FROM SMOOTH SURFACE

FIG. 59*b*.—IRREGULAR REFLECTION FROM ROUGH SURFACE

the spot of light is of nearly the same size as the outline of the mirror's shadow. In the second case, the rays have been separated and scattered. In both cases, *reflection* has taken place; with the smooth mirror there has been *regular* and with the rough paper there has been *irregular* or *diffuse* reflection. Figure 59*a* represents regular reflection and Figure 59*b* represents irregular reflection. The relation of the rays to each other when reflected from a mirror is the same as before they struck the mirror. This is not so in the case of rough paper. When looking at a mirror we see things in the mirror, not the mirror; when looking at the paper we see the paper itself. This may be better understood if we consider that we *see* a source of light such as a candle flame, gas flame, electric light. When light

DIRECT ILLUMINATION

INDIRECT ILLUMINATION
FIG. 60

waves from these come to a mirror, they continue, only in a different direction, and we see the light just as if we were looking straight at it. In the case of the paper each point on the rough surface, because of irregular reflection, becomes, as it were, a new source of light, sending off rays in all directions, so that when we look at the paper we see these separate points.

104. Value of Diffuse Reflection. Diffuse reflection from walls of buildings and other objects produces a blending of the light waves, and makes it possible to see in places upon which no direct light waves fall. The smoother a surface is, the more difficult it is to see it. For this reason books printed on highly polished paper are bad for the eyes because the glare of the light regularly reflected from the polished surface makes it difficult to see the print. Because newspapers are printed on rough porous paper, it is not so tiring to read them. The mellowness of artificial light first reflected to the ceiling and there diffused through the room is very noticeable (Fig. 60). Also the use of the opalescent and ground glass globes produces a softer, more agreeable light.

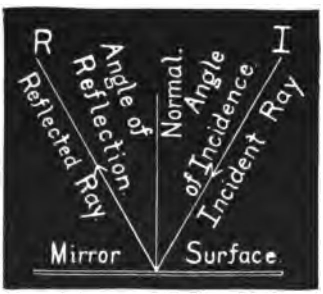


FIG. 61.—REFLECTION OF LIGHT

105. Law of Reflection. If we wish to "see ourselves" in a mirror we must stand directly in front of it. Unless we are so situated we cannot see our image, though others may see it. This is due to the fact that light rays follow certain laws when reflected. Figure 61 represents the law of reflection of a light ray from any surface. *I* is the ray coming to the surface, called the *incident ray*. *R* is the *reflected ray*. The line drawn

perpendicular to the reflecting surface at the point where the incident ray meets it is called the *normal* to the surface. The normal always lies between the incident and the reflected rays. The angle formed by the incident ray and the normal is called the *angle of incidence,* and the angle formed by the reflected ray and the normal is called the *angle of reflection.* The angle of incidence and of reflection are always equal, an increase in one causing a corresponding increase in the other.

The same law of reflection holds for all kinds of surfaces, whether mirrors or not, but it brings about different results in different cases.

Note.—Rays really pass in all directions from the object to the mirror; but in representing what takes place, only the rays shown are considered.

106. Kinds of Mirrors. Mirrors are of two types, *plane* (flat) and *curved.* The curved mirrors may be concave or convex; either a portion of the inside or outside surface of a hollow cylinder or of a hollow sphere, giving us *cylindrical convex* and *concave,* and *spherical convex* and *concave* mirrors. We are all familiar with the plane, and many are familiar with the concave spherical mirrors.

Concave spherical mirrors are of great value in medicine for reflecting light upon the teeth, into the throat, and into the ear. They are used in searchlights and for reflectors of lights in rooms. The images seen in the inside and outside of spoon bowls and in the outside of silver pitchers are examples of reflection from curved mirrors.

Convex spherical mirrors were formerly used to a great extent as hall mirrors, and are now used on automobiles to see the road behind without turning the head.

107. Parallel Rays. While rays from a source of light

diverge in all directions, the amount of divergence of those striking a given area depends upon how far from the source we are considering them. For example, in Figure 62 the rays passing through the successive openings of the cards *I, II, III* diverge least in *III,* the one farthest from the light source. If we go far enough from the source, those passing through the same sized opening will be more nearly parallel. Now the sun is so far away from us that we consider the rays from it as

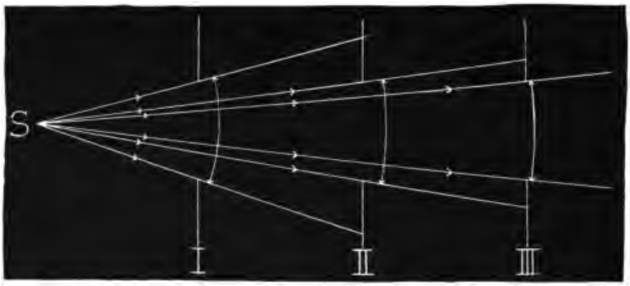


FIG. 62.—THE RAYS THROUGH III ARE MORE NEARLY PARALLEL THAN THROUGH I

parallel. We shall see later that it is possible to change non-parallel rays into parallel rays by artificial means.

If a series of parallel rays strike a plane mirror (Fig. 59*a*) they will be reflected parallel, since the incident rays, as well as the normals, are parallel. If such a series strike a concave mirror (Fig. 67) they will be converging (coming together) on reflection, and in the case of a convex mirror they will be diverging (separating) on reflection. The normals on curved mirrors are the radii of the curves.

108. Images Formed by Mirrors. Whenever rays of light pass from an object to a plane mirror they diverge on reflection, since they were diverging before reflection. The reflected rays

never meet, but seem to come from a point behind the mirror (Fig. 63). The point where a series of rays meet is called a *focus.* The point behind the mirror from which these reflected rays seem to come is not real, and the focus is therefore called a *virtual* or *unreal* one. Each point of the object forms a virtual image, and the combination of these gives what is called a virtual image of the object. In the plane mirror the image of each point appears to be as far behind the mirror as the object is in front, and to lie in a line drawn from a point perpendicular to the mirror. The image of the object is reversed, either from right to left or upside down, and is the same size as the object (Fig. 64).

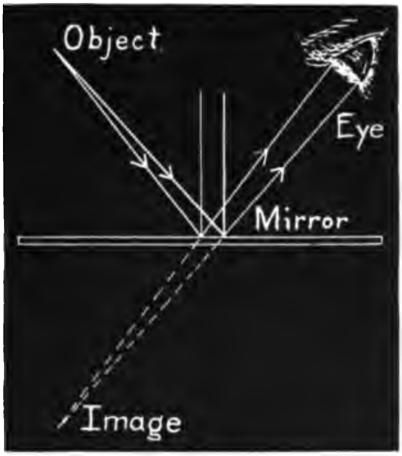


FIG. 63.—IN PLANE MIRRORS WE HAVE A VIRTUAL FOCUS

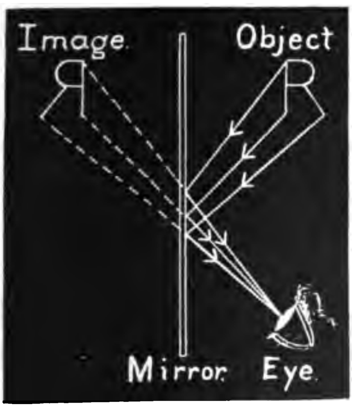


FIG. 64.—IMAGE FORMED BY PLANE MIRROR

A simple experiment to show the location of the image formed by a plane mirror is to set a lighted candle before a piece of glass placed vertically. If a tumbler is set so that the center of its base is as far behind the glass as the candle is in front, it will look as if there were a candle burning in the middle of the tumbler.

In a convex mirror we also get a virtual image, since all rays, on reflection, diverge. This image, however, is smaller than the object (Fig. 65).

In a concave mirror there is a tendency to make the rays converge on reflection. Figure 66 shows the section of a concave mirror. In this figure *m* is the *center* of the mirror, *C* is the *center of the curvature*. The line *C-m*, which passes through the center of the mirror and the center of curvature, is called the *principal axis*, since it divides the mirror into two halves. Any other line through the center of curvature is called a *secondary axis*. The point *F* on the principal axis, where rays parallel to the principal axis cross on reflection, is called the *principal focus*. It lies about half way between the mirror and the center of curvature. Any point

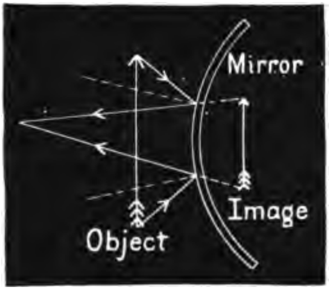


FIG. 65.—CONVEX MIRRORS FORM UNREAL IMAGES THAT ARE SMALLER THAN THE OBJECT

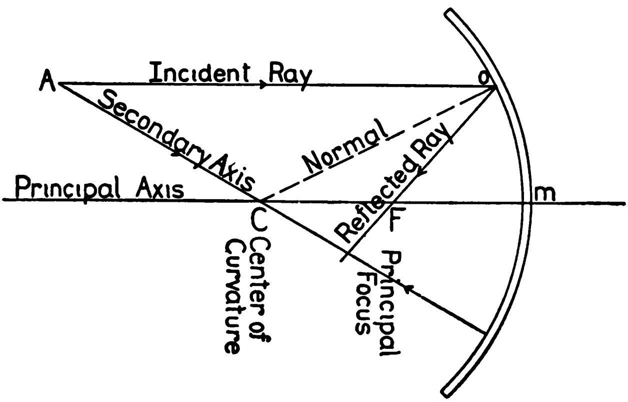


FIG. 66

where other rays cross on reflection is called simply a focus. The angle *A O C* equals the angle *C O F*, as in the plane mirror,

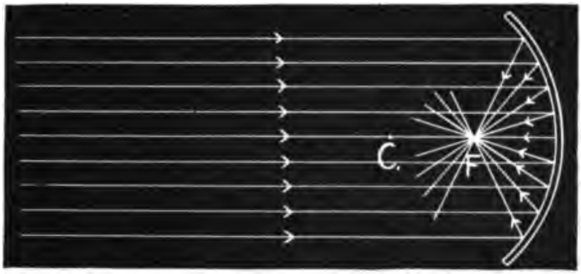


FIG. 67

C O being normal to the curve. (*Note*.—A radius of a circle is perpendicular to the circumference.)

Rays of light coming from the sun are, as before mentioned (Section 107), considered as parallel. Each one of these rays striking a concave mirror will be reflected toward the principal axis, on the other side of the radius drawn to the point of incidence. They will cross or focus at the principal focus (Fig. 67). If we consider the source of the light as coming from a candle flame not far away, the rays will be no longer parallel, but diverging (Fig. 68). Such a pencil of rays will make less angles of incidence than did the parallel rays of Figure 67. They will not, therefore,

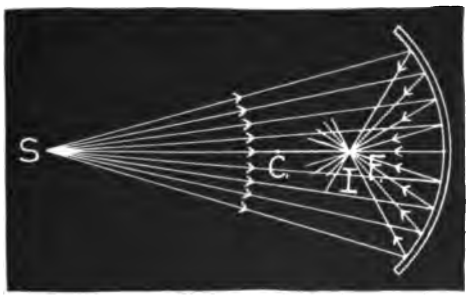


FIG. 68

be bent inwards so much, and will cross or focus at a point farther from the mirror, somewhere between the principal focus and the center of curvature. (*Note.*—The reflected ray must be on the other side of the radius.)

If the light is brought up to the center of curvature, all rays will strike the mirror perpendicularly, and therefore be reflected straight back, focusing at the center from which they started. Should the light be brought nearer the mirror, between the center of curvature and the principal focus, the reflected rays will pass outside of the radii and the focus will be farther away than the center of curvature. When the light is on the principal focus, the rays on reflection will be parallel and never focus. If, finally, the light is brought closer to the mirror, the rays on reflection will diverge and seem to come from a point behind the mirror, thus forming an unreal or virtual image.

Thus far we have dealt with a single point of light. If we now desire to locate the image of an object we locate the images of the two extreme points of the object by the use of two rays, the focus of which determines the focus of all rays from that point of light. These two rays are, one that is parallel to the principal axis and one that passes through the center of curvature. The first passes through the principal focus on reflection, and the second is reflected straight back. In each of Figures 69 and 70 the image of one point is thus located; the

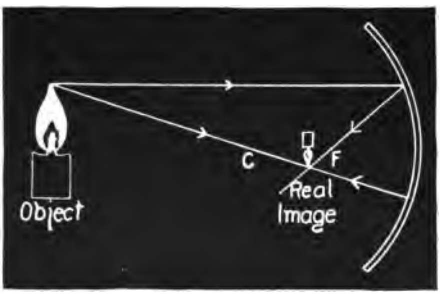


FIG. 69

image of any other point may be found in the same manner. An examination of these shows that as long as the object is beyond the center of curvature the image will form between the center of curvature and principal focus, inverted, real and smaller than the object. If the object lies between the center of curvature and principal focus, the image will form beyond

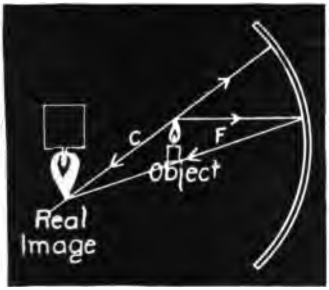


FIG. 70

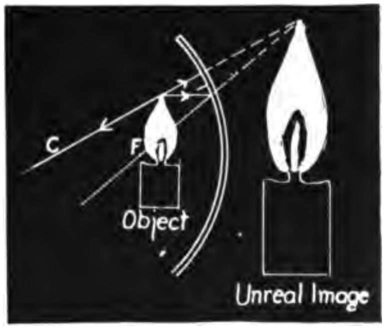


FIG. 71

the center of curvature, inverted, real and larger. When the object is between the principal focus and the mirror, the image forms behind the mirror, unreal, upright and magnified (Fig. 71).

Whether an image is real or unreal depends upon whether or not rays of light *actually* focus. When the rays of light, on reflection, are converging and actually cross at one point, forming a focus, an image forms which can be thrown upon a screen, and be seen by many persons at once. It becomes a source of light, as it were. If, however, rays are diverging on reflection, appearing to come from a point behind the mirror, the focus is unreal. Such images can be seen only by looking into the mirror. They cannot be thrown upon a screen.

109. Conjugate Foci. If the source of light in Figure 68 is S, the image will be at I. *Vice versa,* if the source is at I, the image will be at S. Thus object and image are interchangeable, and the two foci are called *conjugate foci.*

Questions

1. Explain how the north side of a house is lighted when the sun does not shine upon it.

2. What is the objection to the use of highly polished paper for printing purposes?

3. What effect upon the intensity of illumination is produced by the use of diffusers?

4. Explain how light directed first upon the ceiling illuminates a book we are reading.

5. Name two effects produced by the use of ground glass for windows.

6. Sunlight falls upon a mirror lying face up on a table. The word "mirror" is painted upon it with white paint. On the ceiling the same word appears black against a bright background. Explain.

7. Why is it that we can see things on the other side of a window, and at the same time see the image of things on the side where we are?

8. What kind of objects make the best mirrors?

9. Show by a diagram why a person can see the back of his head by using two mirrors.

10. What is the shortest mirror needed in order that a person 5 ft. 6 in. tall may just see the top of the head and the heels of the shoes?

11. How high must the bottom of this mirror be from the floor?

12. As a person moves nearer a plane mirror, does the size of his image change? Explain.

13. Show how a person in a house by means of mirrors may see up and down the street without opening the window.

14. What is the best position for light and book when one is reading?

15. What is the object of putting concave mirrors behind lamps in houses and in the headlights of autos, locomotives, trolley cars?

16. Explain how mirrors may be used to make a room seem longer than it really is.

17. Describe the changes in position, size, and character of the image formed as a light is brought up from a distance until it is close to a concave mirror.

18. Why are some images called real and others virtual?

19. Will a book held in opening *III* (Fig. 62) be as brightly illuminated as in opening *I*? Explain.

20. Why does a dentist use a concave mirror in preference to a plane one in examining the teeth?

21. Why is a concave mirror better than a plane one for lighting the throat or ear?

22. Why does the face look distorted when seen in a spoon bowl?

23. Explain the laughable effects produced when we view ourselves in a curved cylindrical mirror.

24. Draw the image of a clock face as it appears in a mirror at twenty-five minutes after two.

25. Why is it difficult for a person to see the writing on the blackboard at the end of the room when he looks at the blackboard at an angle from the side of the room opposite the windows?

REFRACTION

110. Refraction of Light Waves. That glasses are troublesome to persons when they first wear them can be realized only by those so unfortunate as to need eye correction. When looking sidewise near the edge, they see things double. This is due to the fact that unless light rays strike the surface of the glass perpendicularly they do not continue straight on into the glass,

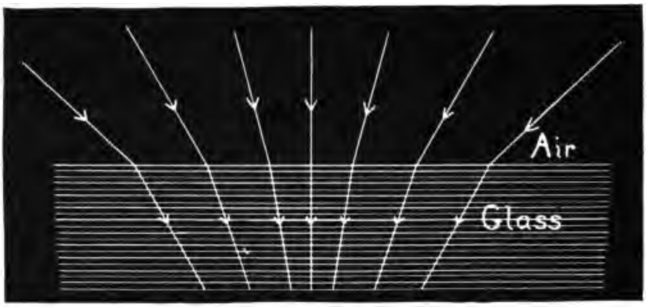


FIG. 72

but are bent. Another example of this is in the bevel of the mirror. When we stand directly in front of the bevel we see a part of our image double, though we see a single image if we move to where the glass is not beveled.

Figure 72 shows the effect produced upon light rays as they strike glass at different angles. Such an effect is known as *refraction.* The amount that a ray is bent or refracted out of its course depends upon what medium it passes from and into what it passes, and upon how great an angle it forms with the surface at the point where the ray enters the second substance. In Figure 73, *I O* represents the *incident ray* and *O R* the *refracted ray.* *I O P* is the *angle of incidence,* and *C O R* the

angle of refraction. Angle $R O D$ represents the amount the ray is refracted from its otherwise straight path. This angle is called the *angle of deviation.* When a ray passes into a denser medium, as from air to glass, it is refracted towards the normal erected at the surface where it enters. If it passes into a less dense medium, as from glass to air, it is bent away from the

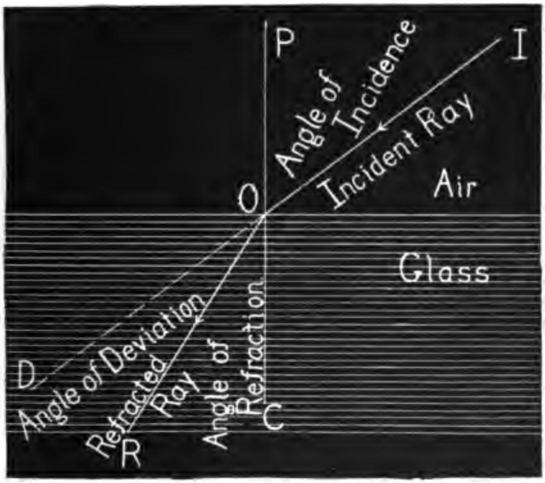


FIG. 73

normal erected at the point where it leaves the denser medium. The normal always lies between the incident and the refracted rays. Figure 74 shows the course of a ray of light through a piece of parallel-faced plate glass. Here there are two incident and two refracted rays and angles; in the passage from air into glass, *a b* and angle *a b e* are the incident ray and angle of incidence respectively; *b c* and angle *f b c* are the refracted ray and angle of refraction. In passing out into the air again on the other side, *b c* becomes the incident ray and angle *g c b* the angle

of incidence, while *c d* and angle *h c d* are the refracted ray and the angle of refraction. Since the two perpendiculars are parallel, the ray, on coming out of the glass, is bent back just as much as it was bent out of its course upon entering. It is shifted, but is parallel to the path in which it was passing before it entered.

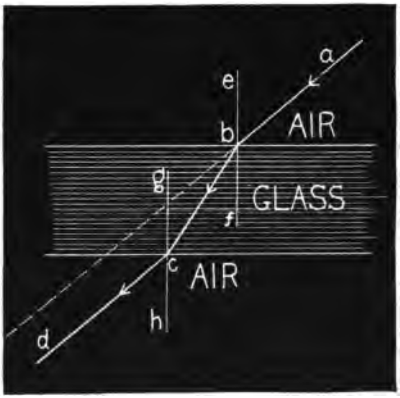


FIG. 74

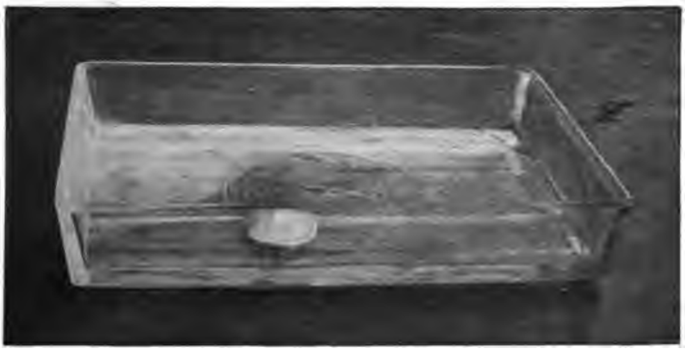
111. Refraction Phenomena. The bottom of a dish filled with water looks much higher up than the table top on which it rests, if it is looked at from above. Water always looks shallower than it is. A stick thrust into water seems sharply bent upwards. A ray of light that in the water passes straight towards the eye is bent to take a path below the eye when it emerges into the air. A coin lying on the bottom of a glass dish, seen only *through* the side, becomes visible *over* the side as well as *through* it when water is poured into the dish (Fig. 75).

Owing to the fact that the earth's atmosphere is a medium different from the ether outside of it, light waves from the sun, on entering it, are refracted towards the earth (Fig. 76). As a result we see the sunrise really before the sun is above the horizon, and the sun seems to set a little later than it really does.

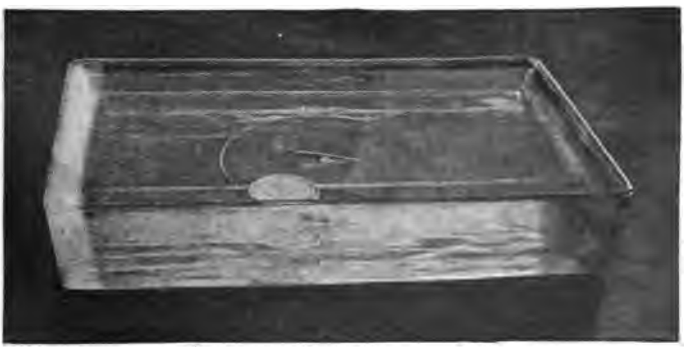
Furthermore, the reflection of the sunlight from the particles in the atmosphere makes the shutting off of the sunlight less abrupt, giving us *twilight*. In the same way we get the effect

of the sunlight in the morning before the sun appears. This effect we call *dawn*.

112. **Cause of Refraction.** The reason that refraction takes place whenever light waves pass from one medium into another is that they move with different velocity in different media.



THE COIN CANNOT BE SEEN OVER THE EDGE OF THE EMPTY DISH



THE ADDITION OF WATER MAKES IT POSSIBLE TO SEE THE COIN IN TWO PLACES

FIG. 75

The relative velocity of light waves in different media is shown in the following table, where air is taken as the standard:

Air,	1.00	Crown glass,	.66
Water,	.75	Flint glass,	.6
		Diamond,	.4

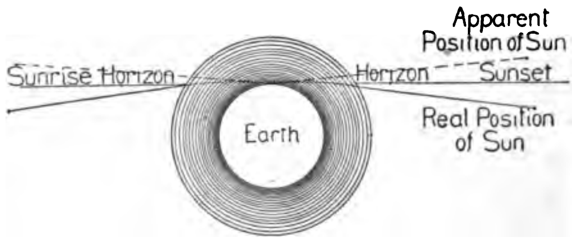


FIG. 76

The greater the difference there is between the velocities of light waves in two substances, the greater is the refraction they undergo when they pass from one into the other.

113. **Explanation of Refraction.** Let the line *x y* (Fig. 77) represent a portion of a wave advancing through the air in the direc-

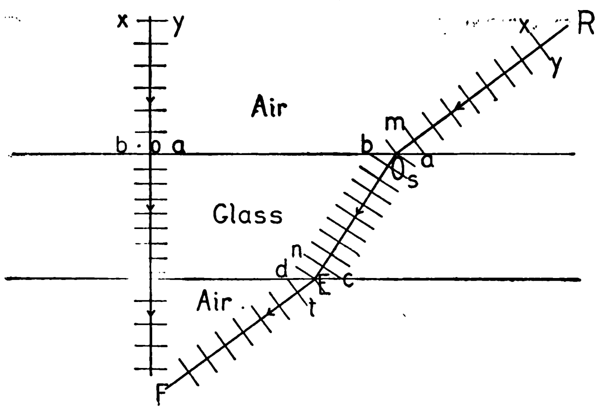


FIG. 77

tion *R O*. Let the spaces between the successive parallel lines represent the distance the wave moves in successive equal time intervals.

If *R O*, the direction in which the wave moves, is perpendicular to the glass, then all portions of the wave will strike the surface *b O a* and enter the glass at the same time. The wave will move with less speed in the glass, but it will continue in the same direction. All parts of the wave will reach the other surface and pass from the glass into the air at the same instant. The speed will now increase, but the direction in which the wave moves will be the same.

If, however, *R O* makes an angle with the surface, the lower side of the wave will reach and enter the glass at *a*, when the upper side is

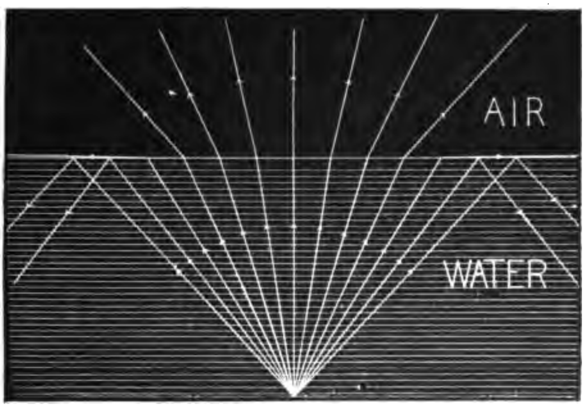
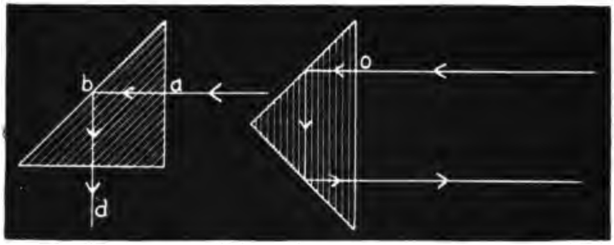


FIG. 78.—TOTAL INTERNAL REFLECTION

at *m*, the distance *b m* away from the glass. The lower side will move more slowly in the glass than does the upper side in the air, so that by the time *m* reaches *b* and enters the glass, *a* has only reached *s*. The front of the wave *b s* is no longer parallel to its front before it entered the glass. It moves in the direction *O E*, which is different from the direction *R O*. The wave moves in this direction until the lower side reaches the glass and passes out into the air at *c*. Here occurs the reverse of what took place when the wave first entered the glass. The lower side moves to *t* by the time *n* moves to *d*, because the speed in the air is greater than in the glass. As a result the front of the wave is *d t* when the whole wave has passed into the air, and the direction of motion becomes *E F*, which is parallel to *R O*.

114. Total Internal Reflection. When light waves pass from a medium outwards into a less dense one, as from glass or water into air, they follow the reverse action in regard to refraction, up to a certain limit. As the angle increases (Fig. 78) a condition is reached in which the ray upon emerging passes parallel to the surface. A ray making a greater angle than this last one is reflected from the under surface just as from a



a *b*

FIG. 79.—TOTAL INTERNAL REFLECTION IN THE RIGHT-ANGLED PRISM

mirror. This phenomenon is known as total *internal* reflection, and the angle at which it takes place is called the *critical angle* for that substance. The critical angle for light passing from water into air is 48.5°; in the case of diamond into air it is 24°; from crown glass into air it is 42°. Such reflection is the most perfect known, and right-angled prisms furnish us with the most perfect mirrors. A ray of light entering at *a* perpendicularly (Fig. 79*a*) passes straight in and is internally reflected at *b*, passing straight out along *b d*. If, as in Figure 79*b*, it enters perpendicularly at *O*, it will be reflected twice and pass outwards parallel and opposite to its direction on entering. Use of this is made in the Zeiss binoculars (Fig. 80), in which two such right-angled prisms cause the ray to pass three times the length of the barrel in going from the large objective glass to the eye-

piece of each barrel. In this way we get, by means of a short length of tube, the equivalent of a telescope. Use of internal

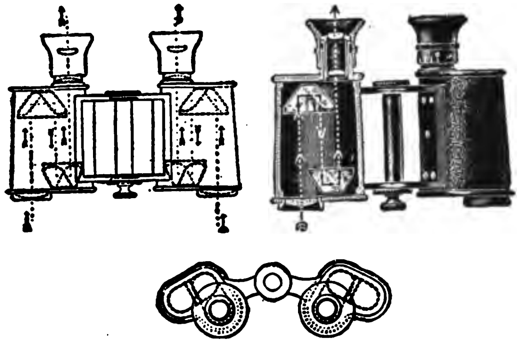


FIG. 80.—ZEISS BINOCULARS

reflection is made in the prism glass reflectors for incandescent electric lamps. By varying the shape of the reflector the light may be directed as desired (Fig. 81).

QUESTIONS

1. Why is a crack in a mirror more apparent when we are not looking at the mirror perpendicularly?

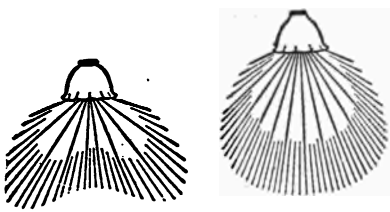


FIG. 81.—PRISM REFLECTORS

2. Why is the image as seen in cheap mirrors so wavy in appearance?

3. In spearing a fish in water, must a person aim above or below the fish as seen from above? Explain.

4. A piece of plate glass is placed over a straight line drawn upon a piece of paper. Explain the different effects (Fig. 82) when it is looked at from different points as indicated.

5. Light is refracted more in carbon bisulphide than in water. Is the velocity of light in this medium greater or less than in water?

6. State the difference between a real and a virtual image.

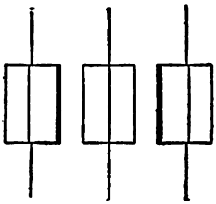


FIG. 82.—LINE AS SEEN (*a*) FROM THE RIGHT, (*b*) FROM IN FRONT, AND (*c*) FROM THE LEFT

7. Explain why a fish in a globe of water looks magnified.

8. Explain why we can sometimes see a double image when looking at a plane mirror that is beveled at the edge.

9. Explain why a stick seems broken upwards when thrust into water.

10. Explain why, when looking down into a tumbler of water, one cannot see the fingers that hold the outside of the tumbler.

11. Show by a diagram the limits of one's "horizon" when looking up from underneath the surface of water.

12. Show how a ray of light may be internally reflected

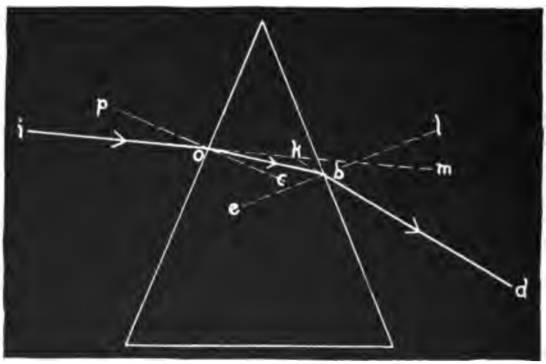


FIG. 83.—REFRACTION BY A PRISM

twice in passing perpendicularly into a right-angled prism the acute angles of which are 70° and 20°.

115. Passage of Light through a Prism. Figure 83 represents a section of a prism of glass. The ray *i o* on entering the glass is bent towards the normal *p o c*, along *o b*. Upon emerging, however, it is bent away from the normal *l b e*. The ray as it leaves the prism is not parallel to the entering ray, as in the case of plate glass, but it passes out in quite a different direction, and goes along *b d*. The angle of deviation is *b k m*.

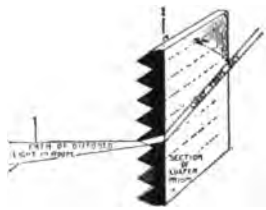


FIG. 84.—PRISM WINDOW-GLASS

In passing through a prism, light waves thus have their general direction entirely changed. The more acute the apex of the prism is, the less will be the deviation from its original path.

Rooms that face light wells or where buildings are close together are made lighter by the use of prism glass windows

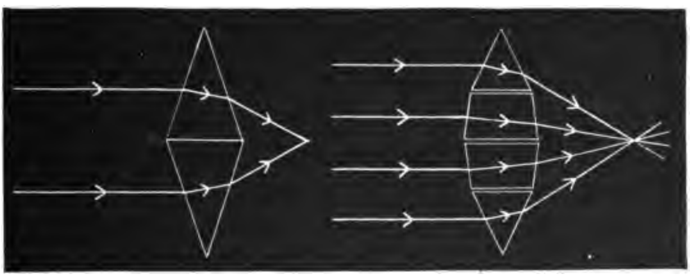


FIG. 85*a* FIG. 85*b*

(Fig. 84), which refract the light waves from above so that they penetrate farther into the room.

If now we take two prisms, one with the apex up and the other with the apex down (Fig. 85*a*), two rays on passing through will be bent towards each other, and cross. If we put

two prisms between these two (Fig. 85*b*), the four rays will cross after passing through. The two middle rays will not be bent so much out of their original path, because they strike the first surface at a less angle of incidence than do the upper and lower ones, and furthermore the sides of these prisms are more nearly parallel.

Should we increase indefinitely the number of prisms, each one slightly different from the next, we should get on each side a surface that is curved (Fig. 85*c*). Such a piece of glass is

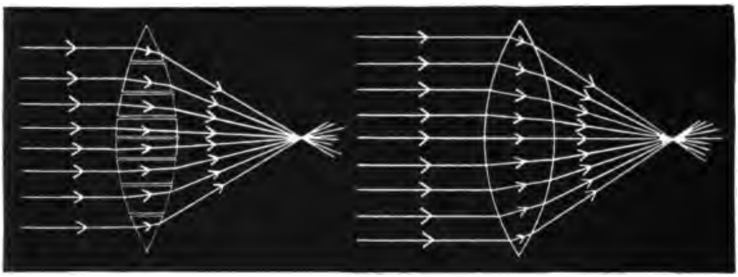


FIG. 85*c*

known as a ***lens,*** which is a transparent medium composed of at least one curved surface and is of different thickness at the edges and center. In most cases the surfaces are spherical.

If we should take two prisms with apices together the rays will be bent away from each other. Increasing the number of prisms in this case will give us a lens that makes the rays diverge (Fig. 86).

116. Spherical Lenses. Lenses may be divided into two different types, those that are thicker at the center than at the edges, known as *convex;* and those that are thinner at the center, known as *concave*. They are called *converging* and *diverging* lenses because of the effect they tend to produce upon rays of

light passing through them. Convex lenses produce converging effects and concave lenses produce diverging effects. Each

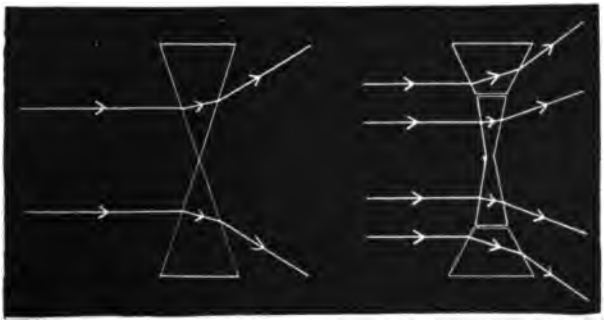


FIG. 86.—DEVELOPMENT OF CONCAVE LENS

general group of lenses is further divided into three kinds, as shown in Figure 87.

117. **Terms Used in Lenses.** Just as in mirrors, so in lenses, the different parts have names. The center of the lens

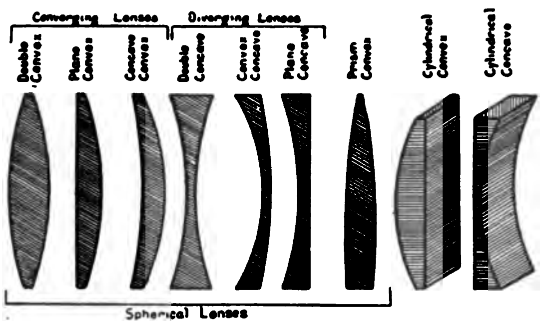


FIG. 87.—TYPES OF LENSES

is known as the *optical center* (Fig. 88). Any line passing through this is an *axis*. Any line passing through the optical center and the center of one curved surface is called the *principal*

axis. Other axes are called *secondary*. In case there are two curved surfaces, the principal axis passes through the center of the other curve. In this case there are two principal foci, each between the optical center and the center of curvature near the latter. Rays parallel to the principal axis, when passing through the lens, are refracted, converge and pass through the principal focus on the other side (Fig. 89*a*). In the case of a concave lens such rays are refracted, diverge, and seem to come from the principal focus on the side from which they

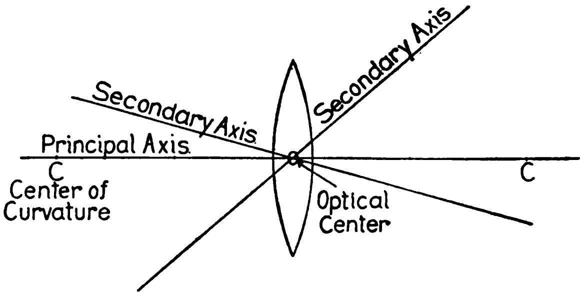


FIG. 88

entered the lens (Fig. 89*b*). Concave lenses never form real images, and they are therefore used only in connection with convex lenses, in order to diminish the converging effect of the latter. The distance from the optical center to the principal focus is called the *focal length* of the lens.

The same results are obtained with convex lenses as with concave mirrors, as far as the kind and size of the image is concerned. The difference lies in the fact that with lenses the light passes through, and refraction, instead of reflection, is the phenomenon. Therefore real images are on the other side of the lens from the object, and unreal images are on the same side as the object. Figure 90 represents the manner in which the

positions of the images are located. Here the secondary axis is through the center of the lens. Two facts must be borne in mind: first, a ray of light passing parallel to the principal axis will be refracted toward the axis when it enters the glass, and

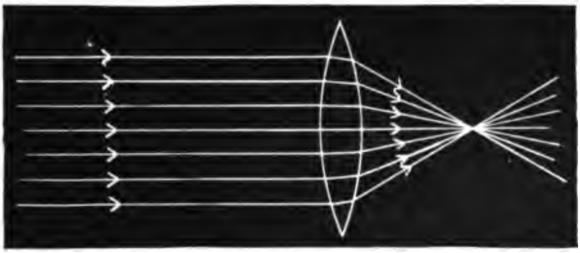


FIG. 89*a*.—CONVEX LENS

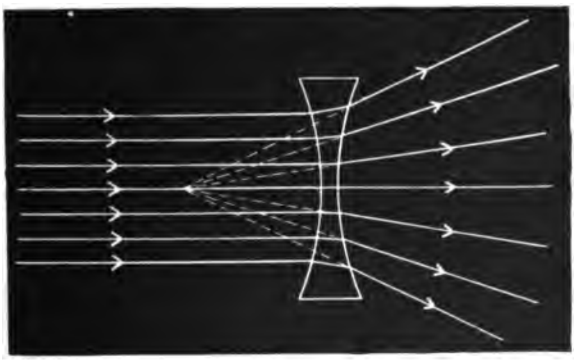


FIG. 89*b*.—CONCAVE LENS

be further refracted toward the axis when it emerges on the other side, finally passing through the principal focus; second, a ray passing through the optical center will be unchanged in direction after passing through. This will, however, be slightly shifted, just as a ray passing through a parallel-sided piece of

glass is shifted. For all purposes of construction, however, it is sufficient to consider the ray as passing through the lens unchanged. Where two such rays cross we get the image of the point from which they originated. By locating the image of the two extreme points of the object we can locate all intervening points by joining these two images.

Now, inasmuch as the farther off an object is, the more nearly parallel are the rays from it, the image of such an object will be near the principal focus of a convex lens. As the object is brought nearer the lens, the image will form farther away. In Figures 90 *a, b, c,* the ray *A I* parallel to the principal axis will in each case pass through the principal focus in the same direction after leaving the lens. This will be the same no matter how near the object is. The secondary ray from *A* through the optical center of the lens will, however, slant downwards more, the nearer the object gets to the lens. The two rays will thus meet farther out on the other side of the lens, as the light is brought up to the lens. When the light is between the principal focus and the lens, the two refracted rays diverge and never come to a focus. To a person looking through the lens they seem to come from a point on the same side of the lens as the light, but farther back. By construction and by experiment it may be shown that with the object more than twice as far away as the principal focus, the image is on the other side of the lens, between the principal focus and a point twice as far away, real, inverted, and smaller than the object (Fig. 90*a*). If the object is between the principal focus and a point twice as far away, the character of the image is just the reverse of the one above, as regards location and size, but is still real and inverted (Fig. 90*b*). If, finally, the object is between the lens and its principal focus, the result is a virtual, upright, magnified image,

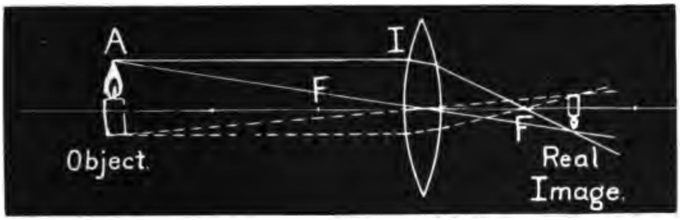


FIG. 90*a*

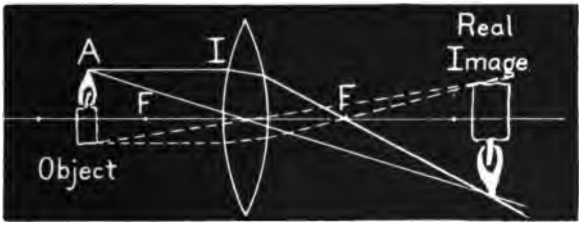


FIG. 90*b*

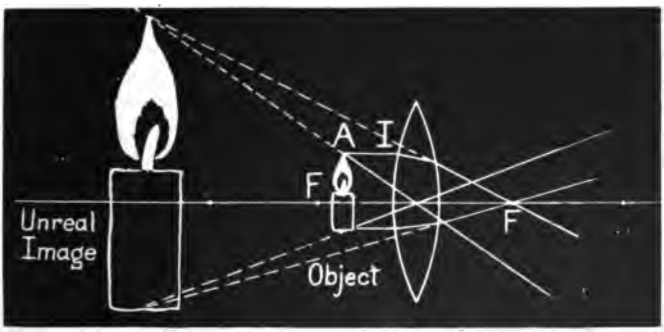


FIG. 90*c*

located on the same side of the lens as the object, but farther away (Fig. 90*c*). In the reading lens, or simple magnifying glass, where the lens must be held near the book or picture (Fig. 91), we find an application of the last case.

OPTICAL INSTRUMENTS

118. Camera. In the camera (Fig. 92), as used ordinarily to secure small pictures of objects, we have an example of the formation of the image of an object more than twice as far away as the principal focus. The image obtained on the screen is real, inverted, and smaller than the object, and lies between the principal focus and a point twice as far away from the lens. The purpose of the bellows on the camera is to keep out all light other than that passing through the lens, so as not to affect the sensitized plate or film. The bellows serves another function. Inasmuch as the camera is to be used for taking pictures of objects sometimes near and sometimes far away, the distance between the lens and plate (or film) must be changed if we wish clear images. This distance will be greater for near objects than for distant ones. The bellows makes it possible to change the distance easily. In order that the photographer may be sure of getting a clear image, many cameras are provided with a ground glass screen upon which the image may be examined.

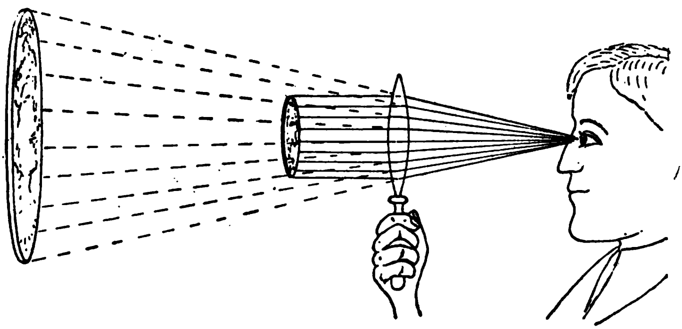


FIG. 91

119. Process of Taking and Making Photographs. Making the Negative. In taking a picture with a camera, we must first *focus* it so that the distance between the lens and focusing screen is such that a clear image of the object forms on the

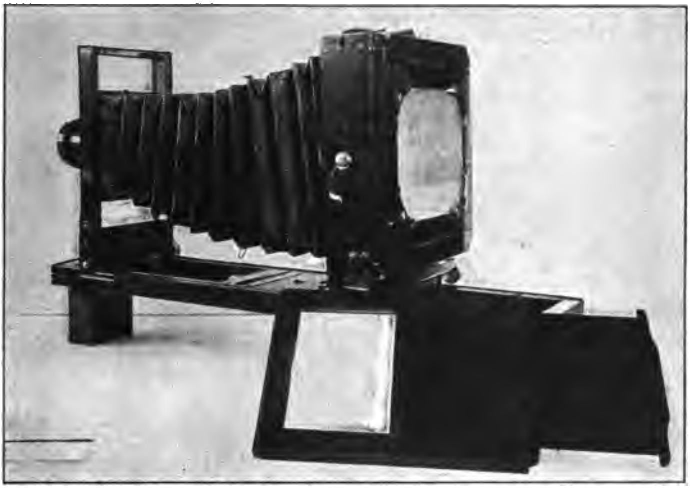


FIG. 92.—CAMERA AND PLATE HOLDER WITH PLATE

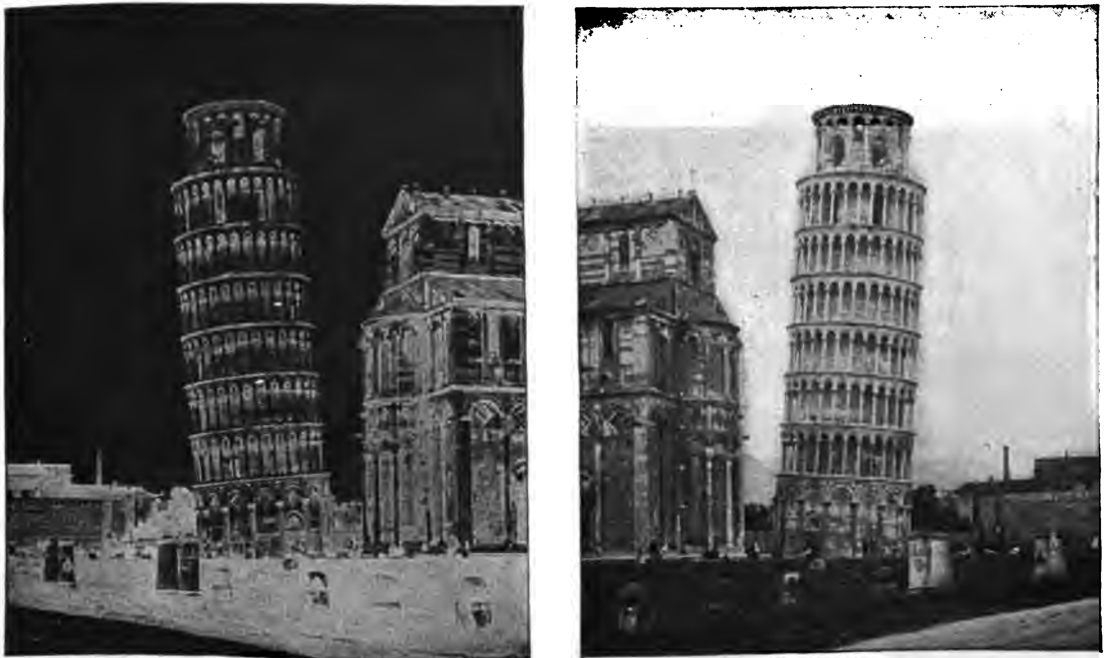
ground glass. A plate holder containing a sensitized plate is then inserted in place of the ground glass, and the opening in the lens is closed either by a cap or a shutter. The slide is drawn from the plate holder and the plate exposed by opening the shutter of the lens or removing the cap. In some cameras (kodaks) a film is used, on which a number of exposures may be taken in succession. In this case there is no opportunity to see if the image of the object is clear, as the film cannot be removed until all the exposures are made. A scale upon the base board must be used in setting the lens at the proper place. As the distance of the object must be estimated, one cannot be

sure that the lens is set at the proper distance from the film to give a clear image.

The sensitive emulsion on the plate is such that where light falls upon it a chemical change takes place. The plate is developed in a dark room under ruby (dark red) light, which does not affect the emulsion. In the process of developing and fixing, those parts of the plate that were affected *most* by the light become nearly black. These represent the high lights of the object, such as the sky and white parts. The parts *least* affected are nearly transparent. These represent the shadows and dark parts of the object. Because the white parts are shown as black and the black objects as transparent, the plate after development is called a *negative* (Fig. 93*a*).

Printing from the Negative. To make a picture from the negative, a sheet of sensitized paper or another sensitive plate is placed against the emulsion side of the negative and light is allowed to fall upon it. Where this is *transparent,* light gets through to the sensitive surface; where the negative is *black,* no light gets through. This printed plate or paper, when developed, gives the reverse of the negative, called the *positive* (Fig. 93*b*). If it is on paper, it is called a photograph; if on glass, it is called a transparency or lantern slide. Films that are used in moving picture machines (see Section 129) are positives.

120. **Human Eye.** In the human eye (Fig. 94) we have a living camera with which pictures are being continually taken, as it were, and transmitted by nerves of sight to the brain, where an impression is made and recorded. In this "camera" there are three refracting media, but for our purpose of discussion we need consider only the lens. This lens is a semi-gelatinous substance that can be thickened or flattened according as certain muscles act upon it. The covering of the eye is composed



(a) Negative (b) Positive

FIG. 93.—LEANING TOWER OF PISA

of muscular coats, the inner lining of which at the back is composed of the sensitive *retina,* which corresponds to the plate in the camera. Now, inasmuch as in a camera the ground glass

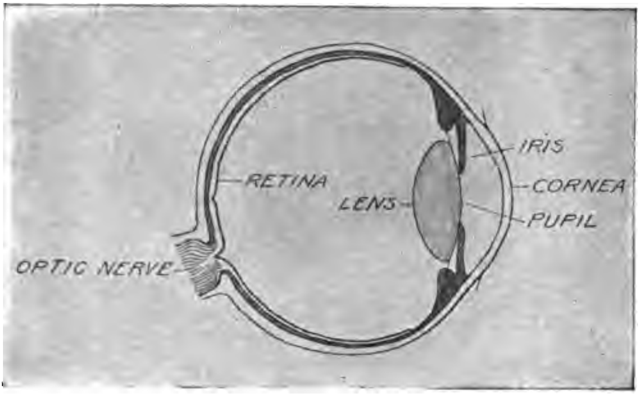


FIG. 94.—HUMAN EYE IN SECTION

must be moved back and forth in order to get a clear image, according as the object is near or far away, so in the eye provision is made, that we may be able to see clearly near and far objects. The shape of the eyeball cannot be changed by any muscular action. It is the lens that changes. A thick lens will form an image much nearer than will a thin one, because the curve is greater and the refraction is greater in the thicker one (Fig. 95). Therefore, when objects are far off the lens is made thin by relaxing the ciliary muscle, and the image forms clearly on the retina. If the object now comes nearer, or we look at a near object, with the lens *thin* the image would form clearly at a point behind the retina, if it could. Thus, where the rays strike the retina they do not focus; so we make the lens thicker by bringing the ciliary muscle into action (Fig. 96), and the image focuses clearly on the retina. This process of changing

the thickness of the lens to focus for near and for far objects is called *accommodation* (Fig. 97). When the ciliary muscle is at rest the lens is thin, so that distant objects can be seen clearly without effort. The ciliary muscle pulls against the suspensory ligament, which relaxes its pull on the lens. The lens then becomes more curved.

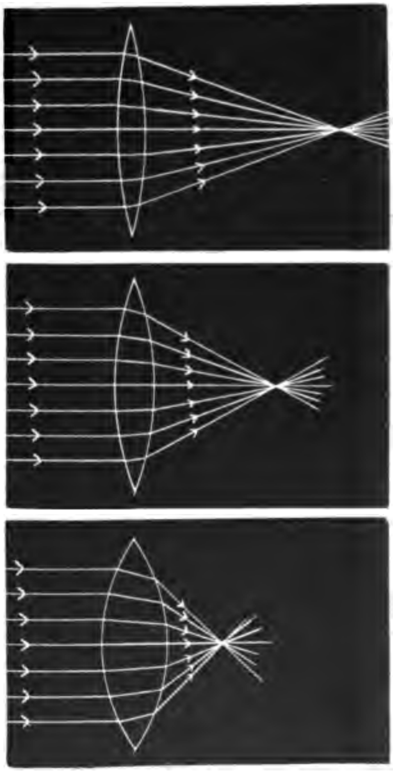


FIG. 95.—THE THICKER LENS HAS THE SHORTER FOCAL LENGTH

121. Defects of the Eye. Many eyes are not normal, owing to various defects. If normal, the eye lens should be such that when the ciliary muscle is relaxed and the lens is thin, images of distant objects form clearly on the retina. In some eyes it is necessary to thicken the lens to get this clear image of distant objects. This is generally because the eyeball is too short from front to back (Fig. 98*a*) and the image tends to form behind the retina. A person in whose eyes this defect is very great experiences too great strain on the ciliary muscles when attempting to read a book, as the muscles are called upon to thicken the lens too much. If their eyes are only slightly defective, it is possible for persons without perceptible effort to see things

at a distance better than persons with normal eyes. This is because they bring the ciliary muscle into action slightly, even in looking off at a distance, and get as a result a very delicate adjustment of the lens, where a normal person is used to seeing fairly well without the use of the muscle. Such eyes are therefore called *farsighted*. To correct this defect, if it is considerable, convex lenses are placed in front of the eye (Fig. 98*b*), producing the same effect that is brought about by thickening the lens.

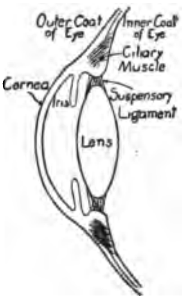


FIG. 96.— ACTION OF CILIARY MUSCLE

On the other hand, some persons cannot possibly see clearly objects far off, but can see near objects well without effort. In such cases the eyes are said to be *nearsighted*. The eyeball is too long from front to back (Fig. 99*a*). As the lens is already as thin as it can possibly be, a concave lens must be placed in front

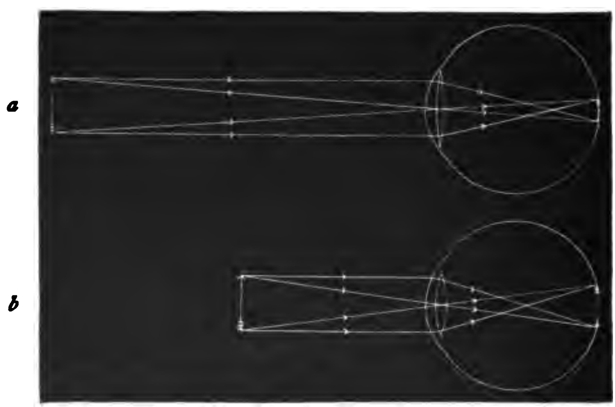


FIG. 97.—EYE LENS ACCOMMODATED (*a*) FOR DISTANT AND (*b*) FOR NEAR OBJECTS

of the eye to make the rays converge less and focus farther back upon the retina (Fig. 99*b*). While such a nearsighted person

a

b

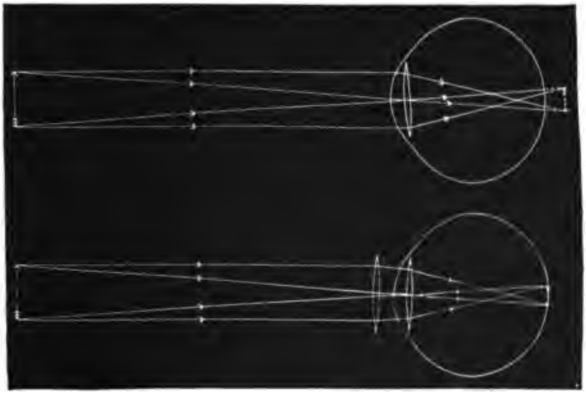


FIG. 98.—(*a*) FARSIGHTED EYE. (*b*) CORRECTION

can see to read without effort, the use of glasses calls the ciliary muscle into action and thus furnishes the exercise necessary in all cases, that muscles may remain healthy and strong.

a

b

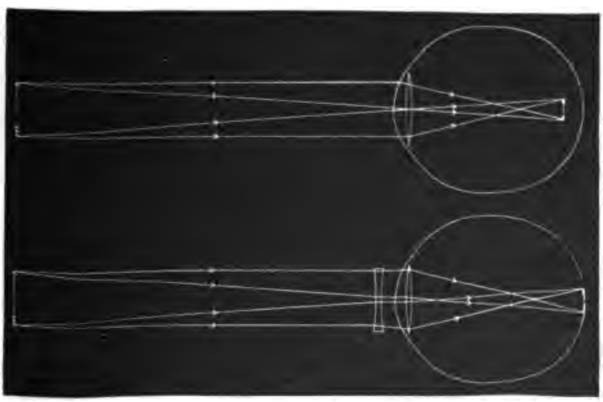


FIG. 99.—(*a*) NEARSIGHTED EYE, (*b*) CORRECTION

122. Astigmatism. This is another common defect in eyes. It manifests itself in one's inability to see clearly at the same time all the lines in a diagram like Figure 100. The cause of this is that the front part of the eye called the *cornea* is not curved equally all over, with the result that the ciliary muscle, which acts uniformly on all parts of the lens, is being continually called into action to focus first for lines in one and then for those in another direction as we read. This quickly tires the muscle and eyestrain results. It is corrected by the use of cylindrical glasses in which the curve sufficiently increases the curve of the cornea at its defective points. In fitting glasses to persons with defective eyesight, the oculist seeks to get those glasses that will make the eye nearly like a normal one. They do not make complete correction, as that tends to weaken the eye.

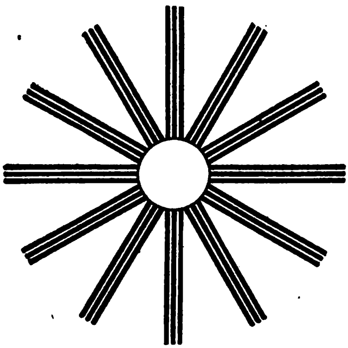


FIG. 100.—LINES FOR DETECTING ASTIGMATISM

123. Binocular Vision. Many think that two eyes are given us as a safeguard against total blindness in case one is injured. The real reason is that with two eyes we can better locate objects than with one. A simple test of this is for a person to let some one hold a fountain pen in front of him, and then, with one eye

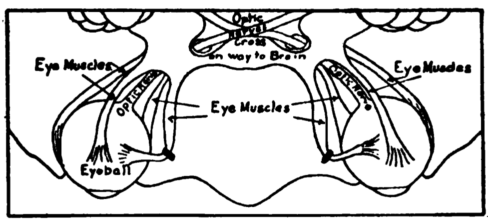


FIG. 101.—MUSCLES THAT TURN THE EYEBALL

shut, try to place the cap over the point. With both eyes open it is a simple matter. The action of the muscles that turn our eyes serves as a means of judging distances, the two inner ones acting more strongly when we look at near objects. The amount of this effort aids us in our judgment (Fig. 101). Sometimes the muscle in one eye is weaker than in the other. To correct this prismatic eyeglasses are used.

124. Blind Spot. There is one other advantage gained by having two eyes. Where the optic nerve enters the back of the eye there is one spot on the retina that is not sensitive to receive an impression. It is

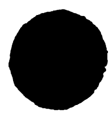



FIG. 102

on the side of the retina toward the nose. Its presence may easily be shown by looking steadily at the black spot in Figure 102 with the right eye closed. If the book is moved until it is about 1 ft. away the + disappears. At 8 in. and at 14 in. it reappears. With the left eye closed, the + must be looked at and the spot will then disappear. This is because the optic nerve enters at the left of the center of the right eye, and at the right of the center of the left eye. For this reason we do not notice the disappearance of objects when the image of them falls on the blind spot in one eye, since the other eye receives the impression.

125. Toric Lens. Of late years the use of the meniscus lens (concave-convex) has been largely substituted in eyeglasses for the flat double convex lens of the same refractive power. In such a curved lens (Fig. 103) the distance of the glass from the crystalline lens of the eye is more nearly equal in all directions, instead of being considerably greater at the edges of the glass than at the center. Thus there is less necessity for a change in the focus of the eye lens when we look sideways or upwards. Furthermore, since the edges are nearer the eyeball our field of vision is increased.

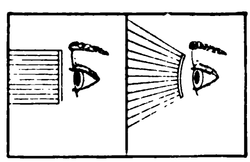


FIG. 103.—USE OF TORIC LENS

126. Stereoscope. It is binocular vision that makes some objects stand out before others and gives what is called depth

FIG. 104.—STEREOSCOPIC PICTURES

to our vision. In ordinary pictures objects seem flat because the picture was taken with one lens. In stereoscopic pictures taken with two lenses side by side, two pictures of the same scene are taken from different points of view (Fig. 104). A careful study of these will show slight differences in them. Such stereoscopic pictures of scenes abroad used to be seen frequently in many homes. With them was a stereoscope in which the pictures were placed. This consisted of two prism lenses arranged as in Figure 105. By moving the card back and forth a point is reached where the two images coincide and the pictures appear as one, with the objects in clear relief and magnified.

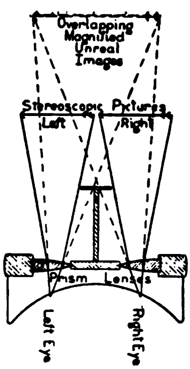
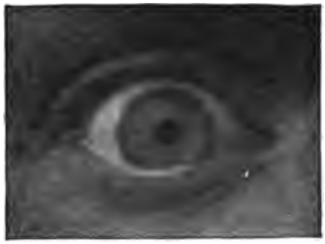


FIG. 105.—STEREOSCOPE DIAGRAM

127. Iris. In the *iris* of the *eye,* which is the colored portion with the dark opening called the *pupil* (Fig. 106), we have a

means of regulating the amount of light that passes into the eye. When the light is strong, the iris contracts, thereby making the pupil very small. Otherwise the sensitive retina might be injured by the too intense light. In dim light the pupil is large, so as to let in as much light as possible, and thus enable us to see better. It is on account of this enlarged pupil that we are dazzled when coming from darkness out into strong sunlight. This condition passes away as soon as the iris closes and the pupil becomes small again. It is the large size of the pupil in the eye of the cat, owl, and other animals at night that enables them to see so well. In the daytime the pupil of the cat's eye is a mere slit.



In Strong Light

In Dim Light

FIG. 106.—PUPIL OF THE EYE

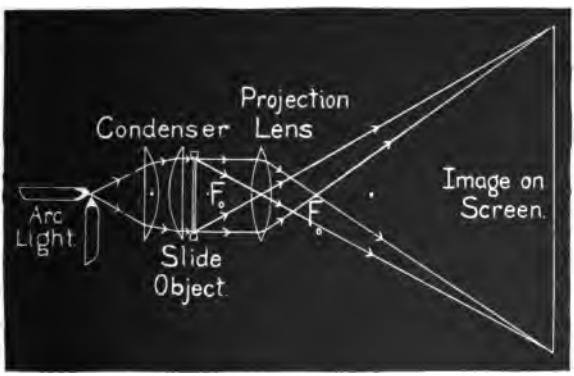


FIG. 107.—PROJECTION LANTERN

128. Projection Lantern. In the projection lantern (Fig. 107) we have the reverse of the camera. Here an enlarged image of a brightly illuminated lantern slide or opaque object is thrown upon a screen for many persons to see. In

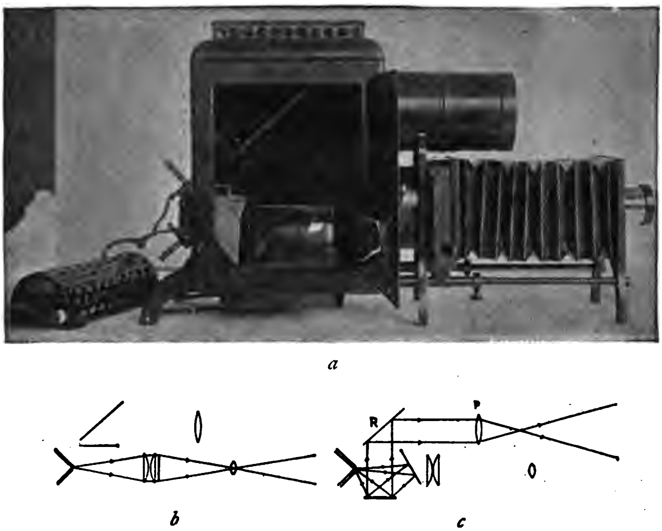


FIG. 108.—COMBINED LANTERN FOR THE PROJECTION OF (*b*) LANTERN SLIDES AND (*c*) OPAQUE OBJECTS

order that the image may be large and upright, the object must be placed upside down, slightly beyond the principal focus. When the lantern is used for lantern slide projection (Fig. 108*a*[1]), the light from the arc falls directly upon the slide which is in an inverted position a little beyond the principal focus of the projection lens (Fig. 108*b*). For the projection of opaque objects such as post cards, photographs, seeds, etc.,

[1] Figure 108 represents a lantern made for household use, in that the source of light is an electric arc lamp that can be operated on an incandescent lamp circuit.

a mirror is lowered to intercept the rays from the arc light (Fig. 108*c*), which are thereby reflected to the opaque object that lies horizontally at the base of the lantern. Rays from this illuminated surface pass upwards to be reflected by the mirror *R*, from which they pass through the projection lens *P* to form an image on the screen.

129. Moving Picture Machine. In this we have in principle a projection lantern. The difference lies in the fact that the picture to be projected is very small, and is continually changed by means of a fast-moving mechanism (Fig. 109). The pictures are slightly different, since they are of moving objects taken in rapid succession (Fig. 110). When thrown upon the screen rapidly the impression of moving objects results. As they change at the rate of sixteen per second, the eye is unable to detect the interval between them.

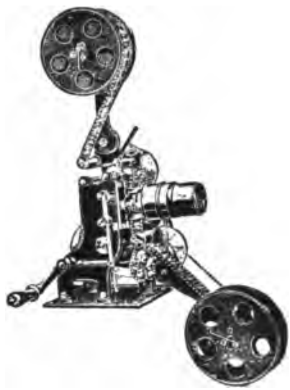


FIG. 109.—MOVING PICTURE MECHANISM

130. Astronomical Telescope. In order to get larger images of distant objects than are obtained with the eye alone, advantage is taken of the fact that the image of anything placed between a lens and its principal focus is magnified. If we first get an image of the object by means of a regular convex lens *O* (Fig. 111), known as the *objective*, we can then place another convex lens *E*, known as the *eyepiece*, in such a position that this image falls inside its principal focus. With the eyepiece so placed, a virtual magnified image of a real image forms. The disadvantage of this method is that the magnified image so obtained will be upside down. With

FIG. 110.—MOVING PICTURE FILM

stars and planets it is immaterial, and telescopes with two lenses so arranged are used for astronomical purposes.

131. Terrestrial or Land Telescope. In the land telescope, in which we desire upright images, the first image as obtained in the above astronomical one must be turned over by means of another convex lens (Fig. 112) and the eyepiece so placed as to magnify this second image. F_o belongs to the object lens, F_I belongs to the inverting lens, and F_E belongs to the eyepiece.

132. Compound Microscope. While the telescope serves to produce magnified images of distant objects, the microscope (Fig. 113) serves to produce magnified images of near objects that are very small. In this case the object is placed slightly beyond the principal focus of a short focus lens. The image that forms is larger, inverted, and more than twice as far away as the principal focus. There is nothing to be gained by turning this image around, so the eyepiece is placed where it will magnify it, *i. e.*, so that the image falls between the eyepiece and its principal focus.

133. Opera Glass. In the case of the opera glass (Fig. 114) compactness is desired. This is secured by placing a concave

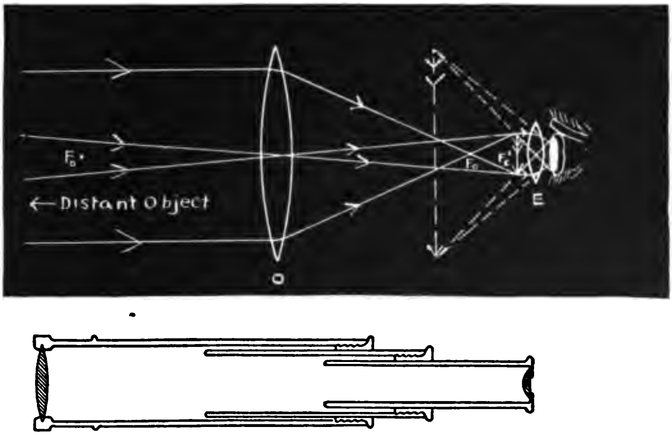


FIG. 111.—ASTRONOMICAL TELESCOPE

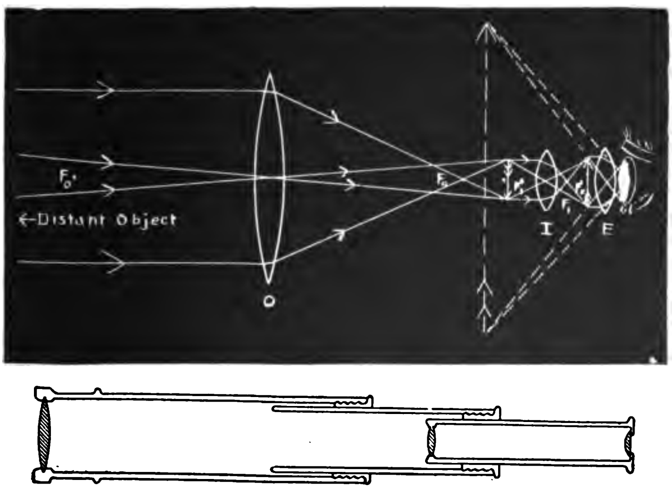


FIG. 112.—TERRESTRIAL TELESCOPE

lens in the path of the rays from the objective before they focus. The effect of this concave lens is to change the rays from converging into diverging ones, producing as a result a magnified upright virtual image of the object. Opera glasses are double tubes and are therefore called binoculars, as are all field glasses. In the Zeiss binoculars (Fig. 80) an added advantage is that by the use of the right-angled prisms an upright image is obtained without the use of the inverting lens. These also make the instrument equal to a telescope three times as long, since the rays pass three times the length of the barrel before reaching the eyepiece.

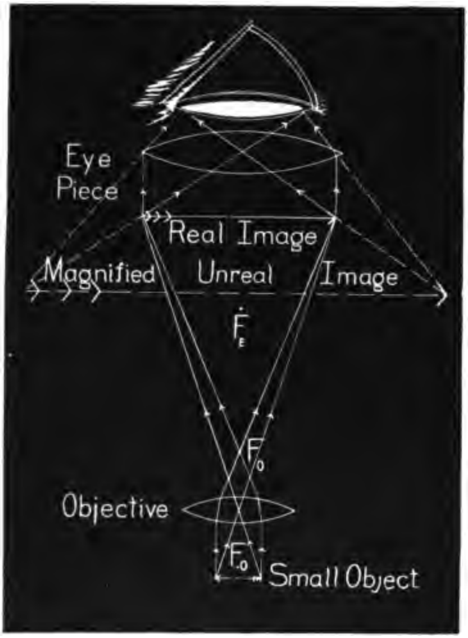


FIG. 113.—COMPOUND MICROSCOPE

QUESTIONS

1. In which case must the plate of a camera be nearer the lens, when taking pictures of near objects or of distant objects? Explain.

2. In a projection lantern, what is the object of using condensers between the light and the slide?

3. Compare the focusing of the eye with that of the camera.

4. Which is more likely to bring on nearsightedness, indoor or outdoor life?

5. In which case will the image thrown upon the screen by

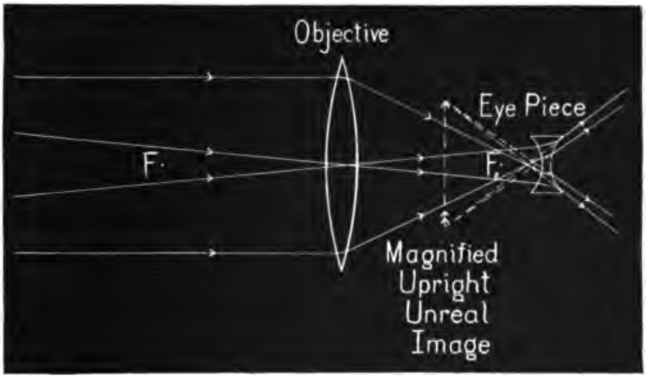


FIG. 114.—OPERA GLASS

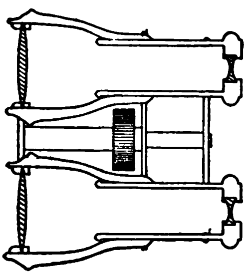


FIG. 114

a projection lantern be larger, when the lantern is near the screen or far from it?

6. Explain the blinding effect produced temporarily when we come from a dark room out into sunlight.

7. Why are two eyes better than one?

8. Why can a cat see better in the dark than can human beings?

9. State two ways of determining by examination of the glasses worn whether a person is near or far sighted.

DISPERSION OF LIGHT

134. Color. In our study of refraction thus far we have only considered the fact that a ray of light passing from one medium to another is refracted. In reality something more has happened. If we allow a ray of sunlight to pass through a prism and place a white screen in the path of the refracted ray, a band of light of several colors appears upon the screen (Fig. 115). This band of colors is similar to that we see in the rainbow,

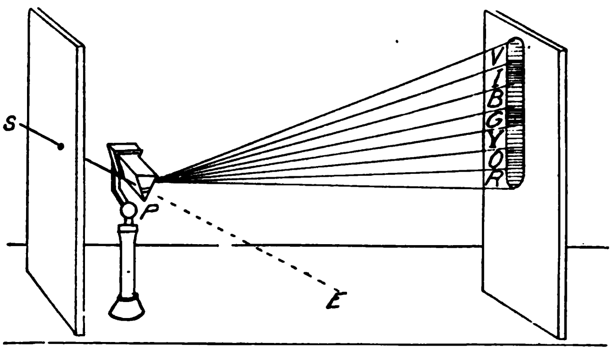


FIG. 115

and is called the *Solar Spectrum*. A similar spectrum may be obtained by using an arc light as our source. The so-called white light of the sun has been broken up into seven colors, red, orange, yellow, green, blue, indigo, violet, known as the elementary colors. Of these the red has been refracted the least and the violet the most. In our previous study (Section 93) we have learned that the slower molecular vibrations produce the longer light waves, while the more rapid ones produce the short waves. The longest red waves are retarded least in the glass and are refracted least. If light waves from other sources than the sun are passed through a prism, a like refraction takes

place, the color of the light on the screen depending upon the color of the waves emitted by the luminous object. From a sodium flame there will be nothing but yellow; from a kerosene lamp the yellow will be brightest; from the Welsbach light we shall get less yellow and more green; from the mercury vapor light the green will predominate. Colors of lights depend upon the wave lengths of the light waves they emit.

135. Color Sensation. According to the modern theory of color sensation, there are three sets of nerves in the retina of the eye, sensitive respectively to red, green, and blue light waves. When these are equally stimulated, white results. If only the red set of nerves is stimulated, red color sensation alone results. Likewise blue when the blue set is stimulated; and green from stimulation of the green set. If more than one set are stimulated at the same time, intermediate colors are produced. These vary according to the proportionate amount of stimulation each set of nerves receives.

Color, whether of lights or of anything else, is a sensation, and depends upon the length of the light waves that come to the eye.

136. Absorption and Reflection of Color Waves. If, instead of a white screen, a dead black surface is used to receive the solar spectrum formed, as in Section 134, there will be very little evidence of color on the screen.[1] The light waves fall upon the black screen but are not reflected to the eye, and no sensation results. Black objects absorb all light waves that come to them and reflect none. White objects, on the other hand, reflect all colors equally and absorb none. Any part of a white surface looks the color of the light waves that come to it. Every part of a black surface is black, no matter what light waves come to it.

[1] The surface must be a dead black.

137. Color of Opaque Objects. Some substances possess the power of absorbing some color waves and reflecting others. *The color we call objects depends upon the light waves that come to them and upon whether or not the waves are reflected.* An object called red reflects red waves best, and absorbs most of the other color waves when white light falls upon it; likewise a blue object reflects blue waves best, and absorbs others. These objects reflect other color waves also somewhat, but the red predominates in the first and the blue in the second. If now the light waves coming to the red object are of a color that the object absorbs, the object will look black, as nothing is reflected. A piece of rough red cloth or paper when held in the spectrum looks red where the red light waves fall, but elsewhere it looks nearly black. A green object looks bright green in the green part of the spectrum where green waves fall upon it, but if it is placed in the other parts of the spectrum the colors are very dim if apparent at all. Prussian blue reflects blue waves very well; also green and violet waves in less degree. All other color waves it absorbs. In white light it looks Prussian blue. In blue light it looks different, as there are no green or violet waves to be reflected and stimulate the eye. In green light it looks green; in violet light, violet. The color in neither of the last two cases is as strong as the blue in blue light.

Similarly a yellow pigment looks different in white light from what it does in yellow light. In green light it looks green and in red light red. In blue light it looks black. This is because it reflects yellow waves best; but also reflects green, orange, and red waves, absorbing all other color waves.

What light waves an object reflects depends upon the light waves that come to it and whether or not it absorbs them. Color is not in objects, as many suppose.

It is on this account that colored materials selected in daylight look so different under artificial light. Some artificial lights lack blue waves, as the kerosene lamp and ordinary fish-tail gas flame; others lack red and yellow waves, as the Welsbach gas light and mercury vapor electric light. Blue cloth in the yellow light of the kerosene lamp looks nearly black, because it absorbs yellow waves.

Clothing and ribbons appear quite different in the daylight from the way they appear in different colored lights cast by fireworks at night.

In the mercury vapor light there are green and blue waves, but no red waves. In such a light our faces look ghastly, as there are no red rays to be reflected by the blood in the face. As the skin reflects green and blue waves, it appears the color of these.

138. Color of Transparent Objects. Just as the color of opaque objects depends upon the light waves they reflect, so the color of transparent objects depends upon the light waves they transmit. The power to transmit varies. The color of the waves it transmits in greatest degree determines the color of a piece of glass, even though it transmits other color waves somewhat. If a piece of red glass is held between the prism and the screen on which a spectrum falls, the screen looks red where the red part of the spectrum is. Elsewhere it looks black. A piece of blue glass absorbs all the color waves but blue and green. The two glasses together absorb all the color waves, and no color appears on the screen, which is now black. A piece of yellow glass transmits yellow light waves freely; green and red waves less freely; blue and violet waves not at all. If blue and yellow glasses are placed together, only green waves will be transmitted by both, and the screen looks green.

Solutions of Ammoniacal copper sulphate and of Potassium bichromate act in the same way as blue and yellow glass respectively, when placed separately or together in the path of the band of color waves.

139. **Compound Colors.** The reason that we get the above results is that it is almost impossible to get substances that have the power to reflect or to transmit colors of one wave length only. While it is perfectly possible to get chemical substances that look the same as any color in the spectrum, we find that this is the result of two or more color waves combined. For example, a mixture of red and green waves gives a yellow that looks exactly like the yellow of the spectrum. Such colors are called *compound* colors, as contrasted with the *pure* colors of the spectrum.

140. **Matching of Colors—Dyeing.** When cloth is dyed, a substance is put into it that has the power to absorb all the color waves of white light except those that produce the desired color. Two pieces of cloth of the same material, dyed at the same time, with the same dye, should look alike in all lights. Two pieces that were dyed with different dyes, labelled the same as far as color is concerned, might look alike in some lights and different in others. Often people match cloth and ribbon in the artificial light of a store, only to find them quite different when exposed to daylight. Here the dyestuff in both reflects the artificial light waves equally, but one reflects in the daylight either the same color waves in different proportion, or an additional color wave that the other dyestuff does not.

141. **Fading of Cloth.** Gradually, when exposed to sunlight, some dyestuffs, through chemical action, change in composition and lose their power to absorb certain color waves. As a result the cloth fades, becoming more nearly white. It is easy

to see why it should approach white and not black, since it reflects more of the light waves.

142. Color Mixing. Figure 116 represents a piece of apparatus for recombining the colors of the spectrum. It consists of seven mirrors fitted on small rotating stands. When placed at the proper position and distance from the prism of Section 134, each mirror will receive one of the seven spectrum colors. By turning the mirrors, these different color waves may be thrown together or separately upon some spot on the white screen. If all are thrown at once we get a white spot formed by the recombined spectrum colors. Red and green combined look yellow. Red, green, and blue produce white. These three kinds of color waves, which produce the same effect as do the waves of all the spectrum together, are therefore called the three *primary* colors. We have here a case of addition of color wave sensations in the eye, stimulating all three sets of nerves. From the proper mixture of these three color waves, any of the other colors of the spectrum may be produced.

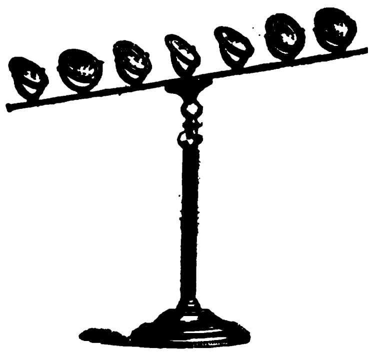


FIG. 116

143. Complementary Colors. Since all seven sets of color waves that go to make up the spectrum together produce the sensation white, it is easy to see that six of them will produce a color effect that together with the seventh will produce sensation white. A great number of such combinations is possible. There is always one compound color that when added

to any given color produces white. Such a pair of colors are called *complementary*. Figure 117 is so arranged that the colors or intermediate colors on opposite sides of the circle are complementary.

Let us take a circular brass disc upon which a piece of white paper has been pasted, and paint one-half of it with Prussian blue pigment and the other half with yellow pigment. Let us whirl this rapidly on the whirling machine (Fig. 118), with white light falling upon it. The resultant color will be white. In this case there has been an addition of color sensations in the eye. Prussian blue reflects blue, green, indigo, and violet waves; yellow reflects yellow, red, and green waves. There has been a rapid succession of color waves of the *whole spectrum* coming to the eye, producing the sensation white.

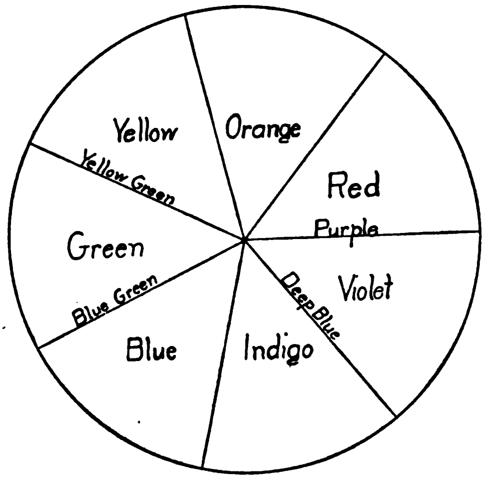


FIG. 117

144. Mixing of Pigments. If upon another piece of white paper we mix the two pigments Prussian blue and yellow, green is the resulting color. Why we do not get white, as when whirling these two pigments together, may be readily seen from the fact that yellow pigment absorbs blue, indigo, and violet waves, while blue pigment absorbs red, orange, and yellow waves.

Together they absorb all but the green waves, which are reflected to the eye and determine the color of the mixture.

Reflected by yellow pigment,	R	O	Y	G			
Reflected by blue pigment,				G	B	I	V

In the case of pigment mixing the process is one of *subtraction* of color waves, not of *addition*, as in the whirling of the colored disc.


FIG. 118.—WHIRLING MACHINE

145. Primary Pigment Colors. Since blue and yellow pigments, when mixed, reflect only green waves, the addition of red pigment, which absorbs green waves, will produce no color, or at least a very indifferent muddy brown. These three pigments, red, yellow, and blue, are called the *primary pigment* colors. It is impossible, by mixing pigments, to get white.

146. Shades and Tints. Thus far we have considered the combining of elementary colors only. If to any color or combination of colors white is added, a *tint* results. In this the color is made fainter, as the power to absorb is diminished by the added substance, white. If the power to absorb is increased by the mixing of a substance that reflects no light, called a black substance, then a *shade* results. In this the color is darkened, and the power to reflect is diminished.

147. Printing in Color. The art of printing in color has been developed to such a high degree that today it is possible to secure reproductions that are almost true to the color appearance of the object they represent. This has been made possible through the three-color process, which has been developed from the half-tone process of printing in black and white.

148. Half-Tone Process of Printing. In this process a negative is made of the picture or object that is to be reproduced. This is made through a screen placed close to the plate, between

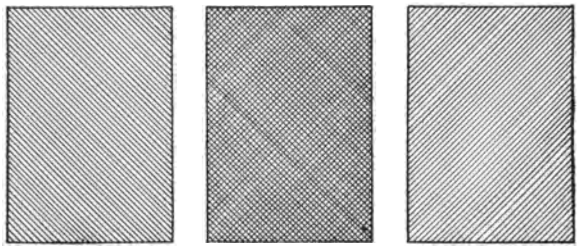


FIG. 119.—SCREEN FOR MAKING HALF-TONE NEGATIVES

it and the lens. This screen is made up of two finely ruled glass plates, on each of which there are from 75 to 200 parallel lines to the inch. The ruled sides face each other in such a way that a series of diamond-shaped openings result (Fig. 119). When the picture is taken, it is the light that passes through these openings that affects the sensitized plate. The negative obtained is not made up of solid masses of black, gray, or transparent parts, but consists of irregular shapes, from fine black dots far apart and surrounded by large transparent areas to portions of almost solid black with fine transparent dots scattered over them. Between these two extremes there are portions that are made up of varying amounts of black and transparent areas.

YELLOW IMPRESSION

RED IMPRESSION

BLUE IMPRESSION

YELLOW AND RED

YELLOW, RED AND BLUE

Figure 120 shows in a magnified form the appearance of the man in the bottom picture of Figure 110, as seen in the negative from which the half-tone plate of Figure 110 was made.

The negative[1] is printed upon a copper plate which has upon it a coating that becomes insoluble in water wherever light waves

FIG. 120

FIG. 121

have acted upon it. When this printed copper plate is washed with water, the bare copper represents those parts where light waves did not pass through the negative, which were the *light* parts of the original object. This bare copper is then etched by

[1] In ordinary photography, where the print from the negative is the final product, the print so obtained would be just as the object looked as far as right and left were concerned. But in the half-tone process the negative must be turned around, because the final printing with ink is done from a metal plate printed from this negative. The film is transferred to another piece of glass, so that what was previously next the glass is now away from it.

a solution that dissolves copper. The parts where the coating was made insoluble are not affected, and remain as projections even with the original surface of the plate. These projections represent the *dark* parts of the original object. Figure 121 shows the magnified appearance on the copper plate of the same part of Figure 110 that Figure 120 represents in the negative. When this copper surface is inked and an impression is made upon paper, the black parts will be made by the projections on the plate. The different projections and depressions are so small and so close together that the eye gets only the general effect of all the separate black impressions. Where the impressions are close together, the print appears black; where far apart, it appears white; while gray results when they are between these two extremes. This may be likened to three squares of equal size, in which dots have been placed. If these are scattered in the first, a little nearer together in the second, and close together in the third, the effect will be white, gray, and black, if they are looked at from a distance.

If Figure 121, which is the positive, is held at arm's length, the outline of the face is not clear; but if the book is placed eight or ten feet away, the appearance is nearly the same as the face in Figure 110, though reversed.

149. Three-Color Process. This differs from the regular black and white half-tone process in that three negatives and three half-tone plates must be made for the one object to be reproduced. These negatives are made, one through a violet piece of glass called a *color filter,* the second through a blue-green filter, and the third through an orange filter. The first negative is dark where the violet waves from the object passed through the filter to the plate. The dark parts of the second represent the green waves, and of the third represent orange

waves. All other color waves are combinations of these three colors, so that some will affect two or more plates, according as they contain more or less orange, violet, or green waves.

Half-tone copper plates are made from these three negatives, and they are then printed, one after the other, upon the same spot. It must be borne in mind that the projections on the copper plate which do the printing represent the parts of the negative *not* affected by the light waves when the picture was taken. These represent the parts in the original object *not* reflecting violet for the first plate, *not* green for the second plate, and *not* orange for the third plate. Therefore the ink used on the first half-tone in printing must be the complement of violet, which is yellow (see Fig. 117). The ink for the second plate is the complement of green, which is red; that on the third plate is the complement of orange, which is blue. These inks must be as nearly pure colors as possible, to get the best results. The colors of the glass filters and of the inks used determine in a large measure how nearly true the results are.

The color plate facing page 143 shows (1) the prints of the three separate plates, (2) the print of the yellow and red together, and (3) the print of the three plates together. Examination of the last one with the microscope will show how the different colored dots lie side by side, producing upon the eye a combined color effect.

Sometimes a fourth negative is made through a yellow filter. Gray ink is used on the half-tone plate made from this. The result of this fourth impression, which is printed first, is a softening effect over the whole picture. Such a fourth impression, though it produces a more pleasing effect on the eye, throws the colors out of their true proportion.

150. **Color Blindness.** One of the sets of color nerves is

often lacking or weakened in a person. Sometimes two sets are affected, and in very rare cases three. To a person lacking in all three, color sense is lacking; light and shade only are apparent. The effect produced upon an eye in which one set is lacking is quite different from that upon a normal eye. A yellow object appears quite green to a person lacking in the red set, since yellow sensation is a combined effect on the red and green nerves. Prussian blue looks bluer to a person lacking in the green set of nerves than to one in whom the nerves are normal. Those who are color blind in the red set of nerves cannot be depended upon in places where danger signals in the form of red lights are used, as on railroads. Color blindness may in some cases account for the startling combinations of colors worn by some persons.

Color blindness is commoner among men than among women. About one man in every twenty-five is affected in one set of nerves.[1]

The test for color blindness is the sorting of a pile of different colored skeins of worsted. A color-blind person puts together into the same pile different colored skeins.

151. **The Rainbow.** Whenever sunlight coming from behind a person falls upon a mist from a fountain or a hose a solar spectrum appears in the mist. In the same way, when sunlight falls upon mist in the sky a spectrum appears. To this we give the name rainbow. Rainbows appear either in the early morning or late afternoon, after a rainstorm has passed over a place. The sunlight falling upon the raindrops as they move away is refracted and internally reflected by the individual drops (Fig. 122). At the same time the light waves are broken up

[1] It is said that the extensive use of tobacco accounts for the large percentage of color blindness in men.

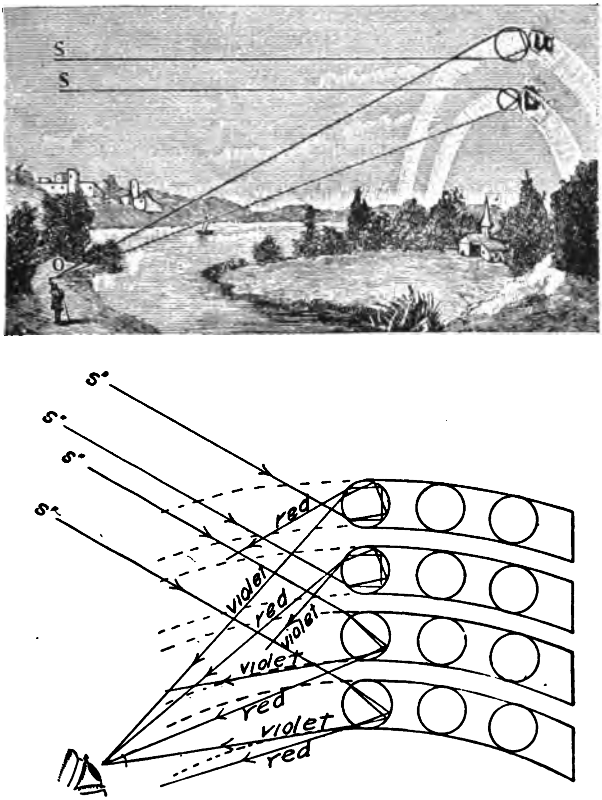


FIG. 122.—FORMATION OF UPPER RAINBOW *U* AND LOWER RAINBOW *L*

into the seven elementary colors which appear in bands on the sky.

While this phenomenon of internal reflection and dispersion of the white light into its elementary colors takes place whenever sunlight falls upon water drops in the atmosphere, the rainbow effect is seen only when the light waves as they come

from the drops pass downward towards the ground. This happens only when the sun is rather low in the sky, never in the late morning or early afternoon.

From the lower drops we get a rainbow in which the red is on top. From the drops higher up a second rainbow appears. In this the red is on the bottom. In the second case the ray of light has been internally reflected upward instead of downward. The semi-circular form of the rainbow can be explained by likening the reflection to that of parallel rays from the surface of a concave spherical mirror, in which all the rays from the sun focus at the principal focus, at which the observer stands. No two persons will see the same rainbow, as a different set of raindrops is acting in each case. The same person sees a different rainbow, if he changes his position.

The play of color seen in the sparkle of the diamond is caused by the same sort of internal reflection and dispersion of light. Diamond has great refractive power and low critical angle. It is cut so as to get the greatest possible amount of this internal reflection.

152. Sunset Colors. We have all noticed the beautiful colors produced at sunset, particularly when there are clouds in the sky. These may be explained as being a result of the combined effect of absorption and reflection of light. The light waves must pass through a greater thickness of atmosphere at sunset than at midday, and therefore there is a greater chance for absorption; and since the rays strike the clouds from below, the opportunity for reflection is greater.

Questions

1. In daylight a piece of cloth looks red. When illuminated by yellow sodium flame, it looks black. Explain.

2. How would a bunch of pansies, held in this same yellow light, appear?

3. What is the appearance of flowers in a dark room?

4. Why do some rooms appear darker than others, even though both are receiving the same amount of sunlight?

5. Are black objects seen because of themselves or because of other objects near by? Explain.

6. A piece of glass called red glass appears red when sunlight passes through it. Explain.

7. How would the above piece of red glass look if held between the eye and the yellow sodium flame?

8. Explain why two pieces of cloth, matched under the green mercury arc light, may not match in daylight.

9. When will a rainbow appear higher in the sky, at 5 or at 6 P.M.? Explain.

RADIATION AS APPLIED TO HEAT AND LIGHT ENERGY

153. **Effects Produced upon Radiant Heat Waves.** Having studied the various effects produced upon light waves, we are in a better position to understand those produced upon the other form of radiant energy, heat waves. Just as in the case of light waves, heat waves may be transmitted, absorbed, reflected, and refracted. The difference lies in the fact that the same substances do not necessarily act the same on both. We must bear in mind that while heat waves themselves are as a rule longer than are light waves, they in turn can be divided into both long and short waves. Those that come from objects that do not emit light waves also are the long ones, while from objects emitting light waves come short heat waves as well.

With these facts clearly in mind, we are in a position to grasp explanations that follow. Let us see first if all hot objects set up heat waves equally well in the ether. If a rough surfaced teakettle and a smooth surfaced one are filled with boiling water and set aside, the rough one will cool off much faster. Likewise if two cups, one rough and one shiny, are filled with hot water a similar effect will be produced. In fact, any rough object cools off (radiates heat) faster than a smooth one. For this reason radiators are always rough, as we wish the heat to get out of them into the room as easily as possible. The bottoms of teakettles are made rough, as it is thus that the heat is absorbed by the water inside. We say then that rough surfaces afford easy radiation and are easy absorbers of heat, while smooth surfaces, which are poor radiators, are also poor absorbers.

Coming to the matter of color in clothing, we have seen that white objects absorb no light waves, while black ones absorb practically all light waves. If we allow sunlight to fall on black cloth, the light waves, being absorbed, are turned to heat and the cloth becomes warmer. With white cloth scarcely any temperature effect is produced. We therefore wear dark clothing in winter when we go out into the sunlight merely to get the full benefit of the light waves from the sun. White cotton and khaki are worn in the tropics for this reason. Because of this conversion of light waves to heat when sunlight falls upon leaves on the snow, holes form underneath, as dark leaves become warmer than the surrounding snow.

Icicles form when the sunlight beats down on the dark roofs of houses, warming them and causing the snow to melt. The water dripping from the eaves gets out from the influence of the warm roof and meets the air that is colder than freezing. It thus freezes a little at a time and forms icicles.

154. The effect of glass on heat and light waves may be shown with a piece of apparatus known as the radiometer (Fig. 123). In this there are four light aluminum vanes mounted upon a delicate frame. One side of each vane is shiny and silvery and the other side is rough and black. The vanes are so placed that when they revolve the rough sides face all one way. The bulb is nearly exhausted of air. When this is held near a Bunsen flame the vanes whirl, with the rough side moving away from the heat. If now a piece of thick glass is placed between the bulb and the flame, the rotation soon slows down. If the holes of the burner are closed, a yellow flame resulting, the vanes at once move faster.

FIG. 123.—RADIOMETER

The explanation of this is that in the first case, where heat waves only were coming to the vanes, the *rough* surface absorbed them faster and therefore became warmer than the shiny surface on the vane at the other end of the cross-piece. The molecules of air next to the rough vane were, as a result, heated more and therefore set in greater vibration. They thus hit the rough vane harder and made it move away. When the light waves came, after the glass shut off the heat waves, the *black* surface absorbed the light waves more than did the white surface, thus again becoming warmer.

155. Cold Frames. While glass and water are transparent to the light waves and to short heat waves, they are nearly opaque to the long heat waves. If, then, we surround a bed of violets with a wooden frame and over this place a tight-fitting glass frame, the light waves passing readily through the glass will be absorbed by the dark earth and turned into heat to warm the plants. The long heat waves set up cannot pass out through the glass, so that by day there is a gradual accumulation of heat which keeps the plants warm through the night in the midst of winter. In the same way the light waves are utilized in helping to keep greenhouses warm.

156. Radiation and Its Effect upon Temperature. Inasmuch as damp air is transparent to light waves, but not to long heat waves, a result similar to that of the cold frame takes place when there are clouds over any part of the earth, and at night the air remains warm. If, however, the air is dry and clear,

radiation of the long heat waves goes on very readily at night, with the result that the earth cools off very rapidly. Thus, with low humidity, the temperature drops below freezing and we have frost. When the fruit growers know that there is likely to be a frost, they burn smudge fires about the trees, and thus furnish a protective blanket of smoke that is opaque to heat waves and prevents that part of the ground under it from cooling off. Plants are covered with newspapers and cloths which, forming a blanket, prevent the cooling off of the ground under them. In a similar way the slow cooling of water and the loss of its heat when it freezes is utilized in the cranberry bogs when a frost is expected; the bogs are flooded with a protecting layer of water.

Questions

1. Why is it that polished fire tongs before a fire are not hot, while the fender is quite hot?

2. Why is the bottom of a teakettle rough while the top is smooth?

3. Which will cool faster, a cup of hot tea or the hot tea in the teapot? Explain.

4. Why are dark colored clothes worn in winter and white clothes in summer?

Review Questions on Light

1. Describe how the height of a building or flagpole may be found by means of its shadow.

2. Explain how a room is lighted by the sun, even though the sunlight does not come directly into it.

3. Make a drawing of the image of a clock face at 8.40 (1) as seen in a plane mirror, (2) as formed on the ground glass of a camera by a convex lens.

4. Red light waves are the longest of the light waves. They have most heat waves mixed with them. Explain why firemen wear red flannel shirts.

5. Is it possible for the moon's shadow ever to cover a whole hemisphere of the earth? Explain.

6. Explain the wavy appearance over a hot stove or on the sandy beach on a hot day.

7. Why do we lift our eyes and look away, from time to time, when reading a book?

8. Why does the size of the pupil of the eye change?

9. How should rooms on the north side of a house be papered and furnished to secure the best lighting effects?

10. Why is there so much difference in temperature between day and night on a desert?

11. Why does blue cloth look nearly black in a kerosene or gas light?

12. Name eight sources of artificial light.

13. Why are sawdust or ashes put on ice? Explain.

14. Why are radiators rough? Does the color make any difference? Explain.

15. Why do we never see rainbows at noon?

16. Why is it so difficult to see into a room from the outside when the sun shines brightly?

17. Why is dull paper best for the pages of books?

18. Why are furnace pipes polished?

19. Why is it generally clear after a long rain?

20. Why is it unwise to read a newspaper or book on moving cars?

CHAPTER IV

SOUND

Origin, Transmission, Effects.
Speed and Intensity.
Reflection.
Musical Sounds and Noises.
  Musical Scale.
Musical Instruments.
  Vibrating Strings.
  Stringed Instruments.
  Vibrating Rods.
  Vibrating Columns of Air.
  Wind Instruments.
  Vibrating Plates and Membranes.
Membranes Set in Vibration by Sound Waves.
Reënforcement and Interference of Sound Waves.
  Harmony and Discord.

157. **Origin of Sound.** Most persons if asked to define sound would say that it is something we hear, just as light is something we see. This is true as far as the sensation itself is concerned. But each sensation has its cause, as we have learned in heat and light. Under certain conditions the sensation of sound results, for it can be produced by clapping the hands together, by striking a bell or a piano wire, by bursting a bag, the air in which has suddenly been squeezed, by forcing air from our lungs between the stretched vocal cords in the throat. If we touch the bell, piano wire, or throat during the time that we hear the sound from them, we find a vibrating

or quivering condition. In fact, we learn that in every instance the origin of sound lies in the vibration of some object. In sound the vibration can be seen or felt, and we do not have to assume it as we must with radiant heat and light, in which the invisible molecules are supposed to be the vibrating source.

158. Medium through Which the Vibrations Get to Our Ears. Just as in heat and light, so in sound, vibrating substances set up waves; the difference being that sound waves are not transmitted by the ether, but by gases, solids, and liquids, things with which we are all familiar. Commonest of these is the air. By means of the apparatus shown in Figure 124, it can be shown that ether is not the medium through which sound waves pass. An electric bell is suspended in the bell jar by means of the coils of wire, which also serve as conductors for the current that rings the bell. As long as there is air in the bell jar, the ringing of the bell can be heard distinctly.

FIG. 124

If we pump out the air the sound becomes fainter, until when the air is nearly all removed the ringing can be scarcely heard, though the clapper can be seen vibrating. If air is now readmitted, the sound gradually increases, until, with all the air back, the ringing of the bell is as distinct as before. Had the bell been rigidly fastened to the glass jar, the ringing could have been heard more clearly during the experiment, because the vibrations would have been imparted to the glass through the metal or wood parts of the bell, and the vibrating glass would have set up waves in the air outside.

159. Manner in Which the Waves Pass through the Transmitting Medium. This perhaps may best be illustrated

by a spiral spring (Fig. 125). If the end A' is struck, there will be a pushing together of the coils at that end. They are thus thrown out of equilibrium. In coming back to their orig-

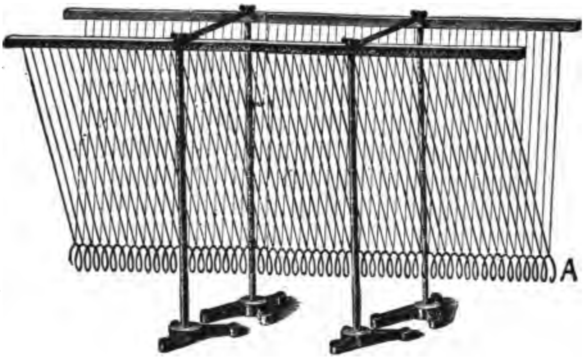


FIG. 125

inal condition they will pass by the starting point and vibrate just as a clamped stick when pulled aside swings to and fro (Fig. 126). The vibration of the coils produces a compression on the next coils, which, going through the same process, impart the effect to the next, and so on. In this manner a wave of successive compressions passes through the spring. Now, in the case of bursting a bag, the compressed air inside, on being set free, produces the same kind of effect on the air outside, air being just as capable of vibrating as is the brass spring. Waves are set up in the air, only they pass in every direction, not from end to end, as in the case of the coil of wire. The waves are said to pass along in the form of *condensations* and *rarefactions* (Fig. 127), brought about by the molecules first coming together

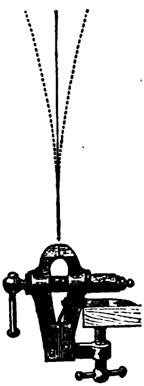


FIG. 126

closer than ordinarily, then rebounding and flying farther apart than before. It must be clearly borne in mind that the molecules do not move along with the waves, but simply, in vibrating to and fro, impart the successive impulses onwards to the next molecules, as do the molecules in transmitting heat by conduction. This may be shown by placing a lighted candle at the small end of the 10-ft. tube (Fig. 128). The waves produced by slapping two books together will put out the flame. The waves pass through the tube in a shorter interval of time than it would take the air molecules to move from one end to the other.

FIG. 127

160. Effects Produced by Sound Waves. If sound waves fall upon the receptive ear, the sensation of sound results. If they fall upon the diaphragm or disc in the phonograph or tele-

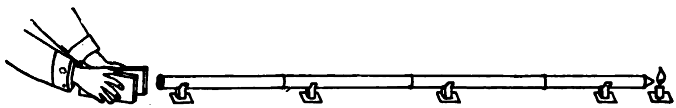


FIG. 128

phone, they set it in vibration. If of sufficient force, as in the case of waves set up by violent explosions, they may even break windows or cause houses to shake.

161. Speed of Sound Waves. Compared with light waves, the speed with which sound waves pass, even through the best media, is very slow, as shown by the table.

VELOCITIES OF SOUND WAVES IN DIFFERENT SUBSTANCES

In feet per second:

Air,	1,100	Pine wood,	10,900
Water,	5,000	Oak,	12,600
Steel,	16,000		

162. Intensity or Loudness of Sound Waves. When a large bell is struck, the sound produced is loudest at first, but gradually dies away as the vibration diminishes. Extent of the to and fro motion determines the *amplitude* of the vibration. When this is greatest the sound produced is loudest.

We have learned (Section 98) that the intensity or brightness of light diminishes as the square of the distance from the source. The intensity or loudness of sound diminishes at the same rate. Sound waves, like light waves, spread out in every direction, covering an area that increases as the square of the distance from the source.

Loudness of sound waves thus depend on (1) the amplitude of the vibration of the vibrating body, and (2) the square of the distance from the source.

"Putting one's ear to the ground" is an expression originating in the fact that one can hear approaching horses, teams, or trains much better in that way than through the air. An approaching train can be heard when far away by listening at the rail. A blow on a steam pipe in any part of a house can be heard very distinctly in every room through which the pipe passes.

QUESTIONS

1. When a block of wood is thrown on the water that is broken up by waves, in what direction does the block move? What does this show concerning waves?

2. Why do soldiers at the rear of a procession headed by a band march out of step with those at the front?

3. Why is it that the persons upstairs hear the shovelling of coal into the furnace in the cellar, while they can scarcely hear the coal being shovelled up from the bin?

4. Give a reason why the velocity of sound waves through solids should be so much greater than through gases.

5. What causes the humming of the bee?

6. Explain the noise of a bullet as it passes through the air.

7. Why does the clapping of the hands produce a noise while there is no effect resulting when they pass by each other?

8. Explain the noise that results when an electric light bulb collapses.

REFLECTION OF SOUND WAVES

163. If sound waves can be prevented from spreading in all directions and concentrated in one direction, the loudness can be increased. Sound waves undergo reflection, just as do light waves, when they encounter a medium different from the one through which they are passing. A sounding board placed above and behind a speaker or band reflects some of the sound waves in one general direction, which thus helps out those naturally going in that direction. In the megaphone and speaking tube we have this reflection phenomenon most advantageously utilized (Fig. 129).

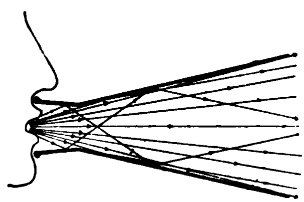


FIG. 129.—MEGAPHONE

It is on account of reflection of sound waves from the walls of a room that a person's voice sounds louder indoors than out in an open field.

Smooth, hard surfaces reflect better than do rough, soft ones. For this reason the presence of furniture, curtains, or human beings in a room deadens the sound by breaking up the waves.

164. Echoes. Sound waves require one second to travel 1,100 ft. in air and the human ear is able to recognize five short syllables a second.

In $\frac{1}{5}$ of a second sound waves will travel 220 ft. in the air. Reflecting surfaces more than 110 ft. away will thus cause reflected sound waves to be heard at the starting point more than $\frac{1}{5}$ of a second after those heard directly. The sound will thus be heard twice. Such a repetition is known as an *echo,* which is a common phenomenon in valleys, the sides of which are smooth and nearly vertical. Sometimes multiple echoes result and the sound is heard many times repeated. If the size and shape of a room are such that the sound waves reflected from wall to wall take more than $\frac{1}{5}$ of a second to return to their origin, we get *echoes.* Echoes in a hall are most objectionable and are often corrected by stretches of cloth so arranged as to interfere with the reflected waves. If, however, the sound waves return in less than $\frac{1}{5}$ of a second, so as not to produce distinct repetitions, a resounding effect known as *reverberation* results. It is because of this effect that empty rooms sound hollow. Halls sound so when empty; but when a room has in it furniture and portières, or the hall is filled with people, the reflection of the sound waves is interfered with and the reverberation becomes much less.

165. Stethoscope. In this instrument also (Fig. 130) reflection is utilized. When in use the large end of this is placed on the surface of the body. The diaphragm or disc is set in vibration by the variations in pressure produced upon the sur-

face, by the noises in the body, or by the heart-beat. The sound waves thus set up in the air in the tubes are reflected back and forth from the walls of the tube and concentrated at the smaller ends, which are placed in the ears of the listener. In this way, abnormal sounds produced by irregularities of the heart-beat or of the breathing in the lungs may be more readily detected.

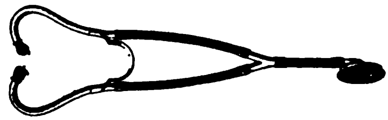


FIG. 130.—STETHOSCOPE

QUESTIONS

1. Why does a person hear better when the hand is placed behind the ear?

2. Why is it so easy to hear whispers in an empty room?

3. Explain the "roar of the sea" heard in large shells held close to the ear.

MUSICAL SOUNDS

166. Musical Sounds and Noises. Sounds may be divided into two classes, depending on the uniformity or regularity of the waves. In the case of waves resulting from the rattling of dishes, from water running from the faucet into the sink, from water boiling in the kettle, from the rumbling of thunder, from wagons rolling on the pavements, the vibrations that set them up in the air are complex and the waves produce a disagreeable result called a *noise*. If the vibrations are of one sort and regular, such as in the case of the vibrating teeth of a comb, as the thumb nail is run across them, we get a *musical sound*. Sound proper deals with the latter.

167. Characteristics of Musical Sounds. We speak of musical sounds as being high or low in *pitch*, loud or soft in *intensity*, and as having *quality*, which distinguishes them from other sounds of the same pitch and loudness. It is this last that enables us to recognize which instrument is being played or who it is that we hear speaking at the other end of the telephone line. It is sometimes figuratively called color.

168. Musical Pitch. If we examine the strings of the piano or the pipes of the organ, we find that the wires and pipes that correspond to the low notes are large and long, while the high notes come from small short ones.

If a pasteboard card is held so as to strike successively against the teeth of the wheel *A* (Fig. 131) when it is made to revolve at high speed, the successive vibrations of the card produce a musical note. With increased speed the pitch of this becomes higher. If at the same time another card is held against the wheel *B*, which has a larger number of teeth, a note of higher pitch results. We thus see that the greater the number of vibrations and consequent waves that are set up in a given time the higher is the pitch produced.

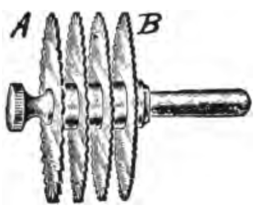


FIG. 131

169. Siren Disc. That pitch rises with increased frequency of vibration may also be shown by the so-called Siren Disc (Fig. 132). In this there are eight circles of holes. (In this figure part of the disc is cut away to show the means of rotation and the impulse attachment.) The outer circle has 48 holes, the next has 45, then 40, 36, 32, 30, 27, 24, respectively. The impulse attachment consists of a piece of metal fastened to a bellows or other source of compressed air. By means of thumb

screws, eight in number, it is possible to direct an air stream against any one of the eight circles of the disc. If we open the inner hole and rotate the disc, a chopping off of the air-stream will be noticed. As the speed of the rotation increases, there will come such frequent chopping that a musical note of low pitch results. With further increase of speed the pitch of this rises. We may vary the pitch by the speed of rotation, which determines the frequency with which the successive pulsations are set up in the air.

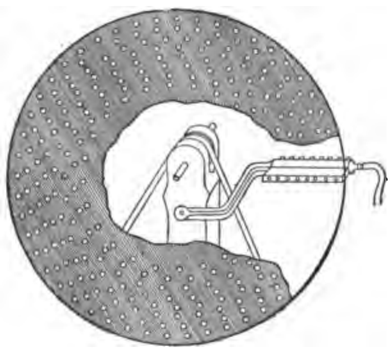


FIG. 132

Let us now see what relation exists between the vibrations set up in the air by the inner and outer holes of the siren disc. If we open the outer and inner holes the notes will seem nearly the same to the untrained ear, though an experienced person will recognize a second note, an octave higher. Here we have twice as many vibrations set up in a second, since there are 48 holes to the outer circle while there are only 24 to the inner circle. If we now shut the outer tube and open the fourth from the outside, which is opposite the circle of 36 holes, we shall get a note that, together with that obtained from the inner, produces a very agreeable sensation. The same holds true if we open the sixth hole, opposite the 30-hole circle, while the inner one is open. We thus see that with vibration frequencies that bear the ratio 24 to 48, 24 to 36, 24 to 30, we get harmonious combinations. These ratios simplified become 1 to 2, 2 to 3, 4 to 5, respectively.

If we try opening together the outer and second holes, which bear the ratio 48 to 45, or the fifth and sixth from the outside, with ratio 32 to 30, the result is very disagreeable.

When vibrations which bear simple ratios to each other act together, *harmony* results. Experiments have shown that three notes with the ratio 4 to 5 to 6 sounded together are harmonious. Three such notes are called a *major triad* or *chord*. Sometimes a fourth note, the octave of the lowest, giving ratio 4 to 5 to 6 to 8, is added.

170. Musical Scale. The musical scale with which most of us are familiar has been built up of three such triads as mentioned above. The diatonic scale is composed of seven notes which connect the two notes an octave apart. These notes are lettered c d e f g a b c′, and are called do, re, mi, fa, sol, la, si, do′. The three triads are do, mi, sol, sol, si, re′, and fa, la, do′. If we place these in their proper places in the scale, the relation that exists between do and the succeeding notes, calling do 1, is as follows:

DIATONIC SCALE

Letters	c	d	e	f	g	a	b	c′	d′
Syllables	do	re	mi	fa	sol	la	si	do′	re′
	4		5		6				
Three triads					4		5		6
				4		5		6	
Ratios in terms of do	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2	$\frac{18}{8}$

In the key of C, in which C is do, which we are now considering, and with which we are all familiar, this note middle C of the piano is produced by 256 vibrations per second.[1] By multiplying this number by the respective fractions indicated

[1] In international pitch, middle C has 261 vibrations, and in concert pitch 274.

for each note, the vibration frequencies of these other notes may be easily calculated, with results as indicated below.

For the purpose of giving intermediate tones, notes have been added between c and d, d and e, f and g, g and a, a and b, giving us sharps and flats, which are represented on the keyboard by the black keys. We have as a result twelve

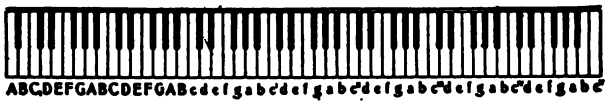


FIG. 133.—PIANO KEYBOARD

notes to the octave on the keyboard (Fig. 133). The intervals between the notes of the diatonic scale are very nearly equal, and serve the purpose just as long as c is the key note. If, however, we attempt to build up a scale with any other key note, as g, we find that of the eight above notes only six will serve; a and f′ are different.

Diatonic key of C

Syllables	do	re	mi	fa	sol	la	si	do′				
Vibration nos.	256	288	320	341⅓	384	426⅔	480	512	576	640	682⅔	768
Letters	c	d	e	f	g	a	b	c′	d′	e′	f′	g′

Diatonic key of G

Syllables	do	re	mi	fa	sol	la	si	do′
Vibration nos.	384	**432**	480	512	576	640	**720**	768
Letters	g	a	b	c′	d′	e′	f′	g′

Tempered scale

Letters	c	d	e	f	g	a	b	c′	d′
Vibration nos.	256	287.4	322.7	341.7	383.8	430.7	483.5	512	574.8
							e′	f′	g′
							645.4	683.4	767.6

We thus need two new notes. If other key notes are used, further notes must be added. To meet all the requirements of our present-day music, we should need about fifty notes to the octave. To overcome this difficulty, the *even tempered* or *chromatic* scale has been introduced. In this there are twelve *equal* intervals between the octaves. The interval between do and mi, the first and third notes of the scale, is called a *third;* that between do and sol, the first and fifth notes, is called a *fifth;* and so on.

MUSICAL INSTRUMENTS

171. Musical instruments may be divided into four classes, according to the character of the vibrating member. In them we have (1) vibrating strings, (2) vibrating rods, (3) vibrating columns of air, and (4) vibrating membranes. Among the first class are found the piano, violin, banjo, guitar, mandolin,

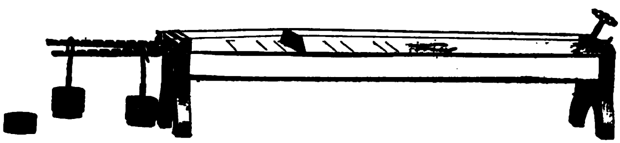


FIG. 134.—SONOMETER

and harp. In the second class come the music box, xylophone, and tuning fork. The third class includes the pipe organ, fife, flute, clarinet, piccolo, bugle, cornet, and trombone. As representative of the fourth class we have the drum, phonograph, gong, bell, and human vocal cords.

172. **Vibrating Strings.** A string tightly stretched between two supports (Fig. 134) may be set in vibration in three ways: (1) by drawing a bow across it, as in the case of the violin; (2) by striking it with a hammer, as in the piano; or (3) by

plucking it, as in the harp, guitar, or banjo. In any case the vibration of the string takes place according to definite laws. For purposes of demonstration a wire is better than a string. If we place a sliding bridge under the wire, the length of the vibrating part may be regulated at will. Experiment will show that a long loose vibrating part produces a lower pitch. A short tight wire produces a higher pitch. A heavier wire under the same tension and of the same length produces a lower pitch. Thus the pitch of vibrating strings depends on three things—length, tension, and size.

173. Vibration of Strings in Segments. If we pluck the wire in the above *sonometer* at its middle point, the whole wire will vibrate and give off a note called its *fundamental*. If, however, we touch the middle to prevent that part vibrating, and bow the wire one-fourth from the end, it will vibrate in halves (Fig. 135), the right half going up while the left goes down. The middle point is at rest and remains so even after the finger is removed. This point of no vibration is called a *node*. The number of vibrations of each half of the wire will be twice as great as before, as evidenced by the pitch, which is the octave of the fundamental note. This note is called the first *overtone*. By damping the wire one-third way from the end (Fig. 136) and drawing a bow across the wire one-sixth way, the wire will vibrate in thirds, giving us the second overtone.

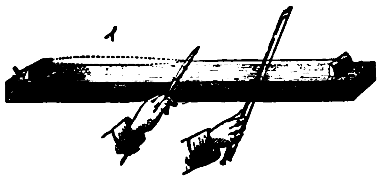


FIG. 135

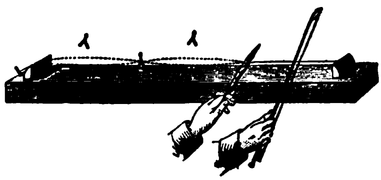


FIG. 136

The piece of paper called the rider at the two-thirds point will remain on the wire, while the other two, half way and five-sixths way, respectively, where the vibration will be greatest, will be thrown off. By proper damping, the wire may be set in vibration in fourths, fifths, etc. (Fig. 137), thereby producing successive overtones or *harmonics*. As we shall see later, it is desirable to have a wire vibrate not only as a whole but also in parts at the same time. Bowing and plucking are therefore never done at the middle, but near the end. In this way overtones sound together with the fundamental (Fig. 138).

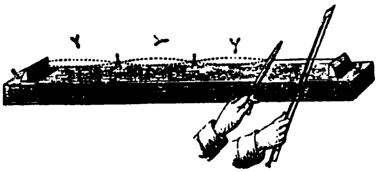


FIG. 137.—WIRE VIBRATING IN FOURTHS

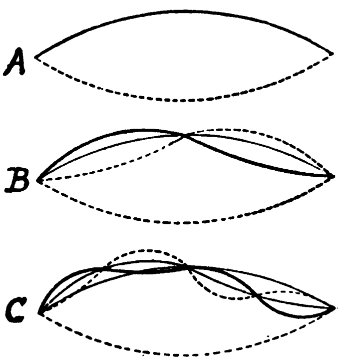


FIG. 138.—A WIRE MAY VIBRATE AS A WHOLE AND IN PARTS AT THE SAME TIME

174. Piano. In this instrument (Figs. 139 and 140) there are many metal strings or wires, often in sets of two or three for each note. Each string has its own fixed length. The strings are set in vibration by a felt-covered hammer controlled by a key. When the key is released a felt damper falls back against the wire and the vibration ceases. The pedals, loud and soft, are to increase and decrease the duration of the vibration of the wires. The loud pedal pulls away all the dampers, so that the wires continue to vibrate for some time. The soft pedal brings the hammers nearer the wires,

so that they strike with less force. The wires are struck one-seventh the distance from the end, so as to produce as many overtones as possible.

Fig. 139.—Piano with Front Removed, Showing Keys and Hammers

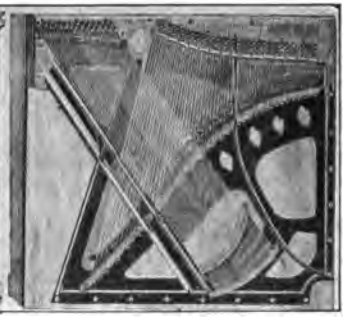


Fig. 140.—Piano Frame, Showing Wires and Sounding Board

175. **Violin.** This instrument (Fig. 141) has but four strings. By a process called *fingering* or *stopping*, one string is made to do for many notes. This is attained by pressing on

Fig. 141.—Violin

the string at different points, thereby changing the length of the vibrating part. Experience enables the player to know exactly where to press the finger to get the desired pitch.

In the banjo, guitar, and mandolin (Fig. 142) there are ridges, called *frets,* which guide the player in locating the point where the stopping should take place.

Fig. 142.—Mandolin, Guitar, Banjo

176. **Harp.** In this instrument (Fig. 143) the strings are plucked. Pedals serve to change the tension upon the strings so as to produce intermediate notes (sharps and flats).

Fig. 143
Harp

177. **Use of Sounding Box.** In all forms of stringed instruments the waves set up by vibrating strings alone would be few and the sound would be thin and weak. In the piano, violin, mandolin, guitar, the strings pass over a bridge, which rests upon the surface of a sheet of thin wood called a sounding board. Whenever the strings vibrate, these boards are set in vibration, and they, because of their larger area, produce a much greater effect in setting up waves in the air. These boards in the violin, guitar, and mandolin form a part of a

sounding box, the front and back of which are connected by a *sounding post* (Fig. 144). In this way both boards are set in vibration together. The quality of the tone of any instrument is determined by the number of the overtones that are present and by the proportion in which they are combined

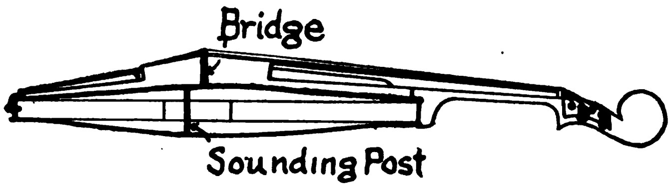


FIG. 144.—SOUNDING BOX AND SOUNDING POST

with the fundamental note. Shape, quality of material, and arrangement of parts all enter into this.

In the upright piano the sounding board is vertical. Because of this, and the fact that the piano is placed with its back to the wall, there is much less opportunity for the free outward movement of the waves than there is in the case of the grand piano. In the latter, with the cover raised and forming a reflector, the full volume of sound is secured.

QUESTIONS

1. Which string of the violin is smallest, the one of highest pitch or the one of lowest pitch?

2. How may the pitch of a violin string be raised?

3. What effect is produced by winding wire upon a string?

4. How are piano wires tuned?

5. Why is it more difficult to learn to play well upon a violin than upon a mandolin or guitar?

6. Why is a grand piano used in preference to an upright one in large rooms and concert halls?

7. Explain the difference in pitch resulting when a rubber band is stretched between the teeth and the fingers and then plucked under different tensions.

VIBRATING RODS

178. Vibration of a Rod One End of Which Is Free to Move. In the music box we find an instrument consisting of a set of metallic rods or teeth of different lengths, fastened at one end (Fig. 145). The free ends are set in vibration when snapped by pins projecting from a revolving barrel, and emit musical notes, the pitch of which depends upon the length of the rod. The shorter teeth emit the higher notes. In this instrument we have an example of a vibrating rod one end of which is free to move, while the other is fastened to a fixed base.

FIG. 145.—MUSIC BOX

179. Vibration of a Rod Both Ends of Which Are Free to Move. Let us shake a stick 6 ft. long and ¼ in. square by holding it at points 1 ft. from each end with the thumb and forefinger. The rod vibrates, the middle portion rising while the two ends fall (Fig. 146). The two points held in the fingers

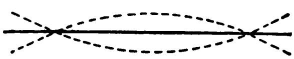


FIG. 146

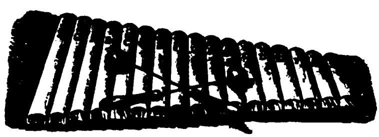


FIG. 147.—XYLOPHONE

do not vibrate. We have here a vibrating rod with three vibrating parts and two nodes. In the xylophone (Fig. 147) advantage is taken of such a mode of vibration. Bars of wood rest upon two supports which lie under the points one-sixth of the length from each end. When such rods are struck at the middle they vibrate, nodes forming where the bars are supported. By using a set of bars of proper length a musical scale can be produced.

180. Tuning Fork. If a rod such as described in the preceding paragraph is gradually bent as indicated in Figure 148*a*,

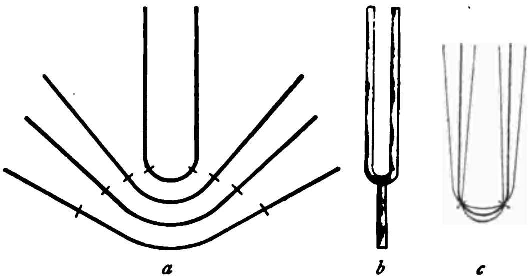


FIG. 148.—TUNING FORK

the nodes come nearer together. If we use a bar of steel about ten inches long, bent so that the sides are parallel, and fasten a handle to the middle part (Fig. 148*b*), a tuning fork results. When the ends or *tines* of such a fork are set in vibration, the middle point rises and falls (Fig. 148*c*).

When held alone the vibrations of the tuning fork make very little impression, but when the handle rests on a table, door panel, or other large surface, the vibrations set up in the table intensify the sound, just as did those of the sounding box of the violin. Such vibrations are known as *forced vibrations*. Owing to the fact that a tuning fork gives off only its funda-

mental note, it is used as a standard of pitch for tuning other instruments. It is sometimes mounted on a box of definite shape and size, to get the greatest possible effect from it (Fig. 150).

181. Vibrating Columns of Air—Resonance. If such a tuning fork as above described is held over a jar (Fig. 149) and water is poured into the jar, there is one time when the level of the water is such that the note from the tuning fork becomes quite loud. In this case the column of air is of such length that it vibrates in unison with the fork; that is, the sound wave passes down the tube, is reflected by the water, and returns to the fork in exactly the same time that it takes the fork tine to make one swing. The air wave thus reënforces the note of the fork and the phenomenon is called *resonance*. If this column of air is set in vibration by some other means, as will be explained later, it will in itself emit a note of the same pitch as the tuning fork. If the tuning fork is mounted on a box in which the air column vibrates in unison with the fork, the note resulting when the fork is struck will be much fuller than when the fork is placed on the table. As different sized tuning forks vibrate at different rates they are mounted on different sized resonators (Fig. 150).

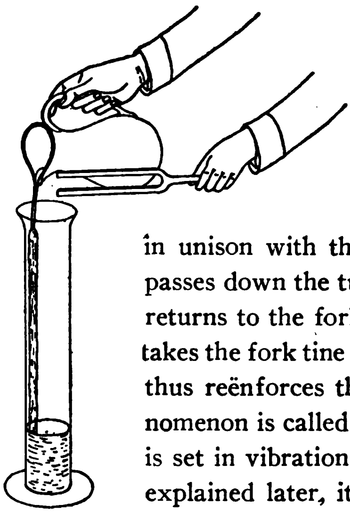


FIG. 149
RESONANCE

182. Sympathetic Vibrations. Very often when certain notes are played upon a piano, violin, or other instrument, vases are set in violent vibration. If two tuning forks of exactly the same pitch, mounted on resonators, are placed near each other

(Fig. 151), vibrations set up by one cause the other to vibrate. If the vibrations of the first fork are now stopped, the second will be heard still vibrating and giving off the same note as did the first.

In this case the sound waves from the first box have set in vibration the air column in the second. This results in the vibration of the handles of the fork, which may be shown by letting a suspended pith ball rest against the second fork. This will bound off when the first fork is set in vibration.

FIG. 150.—MOUNTED TUNING FORKS

If a piece of wax is put upon the end of the second fork and the experiment repeated, there will be no response on the part of the second fork, as the fork with the wax on it vibrates more slowly, and is no longer in tune with the first fork.

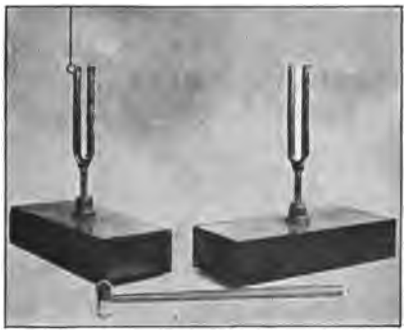


FIG. 151.—SYMPATHETIC VIBRATIONS

Similarly, if the note middle C is sung into the piano when the loud pedal is on, the middle C wire will be found vibrating. Any other note sung will cause the wire of corresponding pitch to vibrate.

Such vibrations set up in objects, the vibration frequency of which corresponds to the note sounded, are called *sympathetic vibrations.*

WIND INSTRUMENTS

183. Principal upon Which Wind Instruments Act. From the above discussion of resonance and sympathetic vibrations it is easy to see that if a complex wave made up of waves representing different pitches should come to a certain resonator, the air column in it will respond only to the waves of the same frequency as those that it would set up itself. A simple experiment with pill bottles of various sizes shows this. When we blow across the mouth of the bottle (Fig. 152) it gives off its characteristic note; the smaller the bottle the higher the pitch. In this case, out of the various vibrations set up by the mouth of the bottle as the air passes across it, the air column in the bottle has responded to only one pitch.

FIG. 152

Wind instruments, depending for their action upon vibrating columns of air, are divided into three types, *air jet, reed,* and *lip* instruments.

184. Air Jet Instruments. As representative of this type of instrument, we have the common whistle and certain pipes of the organ. In these (Fig. 153) the air passing through the tube *t* of the mouthpiece is broken up and set into a fluttering condition when it strikes the edge of the lip *L*. The air column in *r* resounds to its own vibration frequency and a note results. The pitch of this is determined by the length of the air column. In the flute and fife (Fig. 154) air from the lungs is directed by the lips of the player across an opening. The edges of the hole break up this air stream, as in the case of the

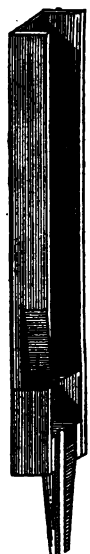


FIG. 153

pill bottle. The air column resounds to the waves of its own vibration frequency. In ordinary whistling, the mouth cavity

FIG. 154.—(a) FIFE, (b) FLUTE

forms the resonator, the lips setting up the vibrations as the air passes out.

185. Reed Instruments. In the harmonica or mouth organ (Fig. 155*a*) a set of thin metal strips serves to break up into puffs an otherwise continuous stream of air that passes through an opening. The musical effect is similar to that produced by the holes of the siren disc (Section 169). The difference is that the siren disc was set in motion by another force than the air, while the metal strip of the harmonica is set in vibration by the air itself as it passes through. This thin metal strip is called a *reed*.

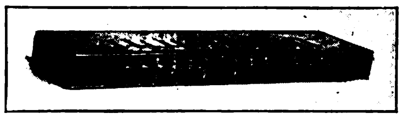


FIG. 155*a*.—HARMONICA

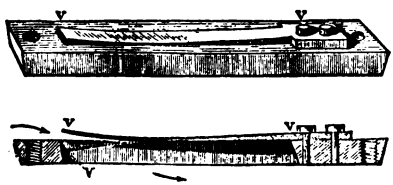


FIG. 155*b*.—REED

Figure 155*b* shows how the air passes as such a reed *V* vibrates in the opening. By the use of strips of different lengths all the notes of the scale are produced. In this form of reed the whole effect is produced by the chopping of the air stream.

In the jew's-harp the reed is set in vibration by the fingers. When this is held before the open mouth, the air cavity of the mouth acts as a resonator. By changing the size and shape of this cavity, notes of different pitch result. In some cases, as in the clarinet mouthpiece (Fig. 156), the reed does not swing *through* the opening.

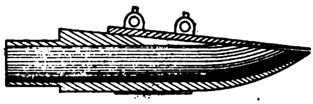


FIG. 156.—CLARINET MOUTHPIECE

In the reed organ pipe (Fig. 157) the reed swings to and fro, as in the harmonica. The difference lies in the fact that there is in this a column of air *B A* to act as a resonator, and greater fullness of sound results.

186. Organ Pipes. In the case of wind instruments the vibrations of the air column take place in a direction along the length of the tube instead of transversely, as in the case of stringed instruments. Inasmuch as organ pipes are made either with both ends open or with one end closed, they may be used as representative of all wind instruments.

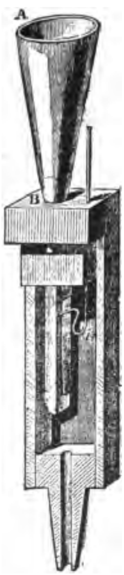


FIG. 157

The tube (Fig. 158) may be used to illustrate the organ pipe. In this an *open* or *closed* pipe effect can be produced at will. Also the length of the closed pipe can be regulated by the sliding piston. With the open pipe the fundamental note is an octave higher than when the lower end is covered with the finger.

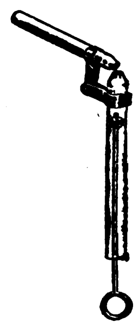


FIG. 158

If a small disc containing a light powder, and suspended by a rod, is lowered into a glass-

walled *open* pipe while the pipe is sounding (Fig. 159), we see that the powder is agitated until the disc is lowered to a point halfway down the pipe. This is the point where there is no vibration of the air, and it is called a *node*. The vibrations are greatest at the two open ends and least at the middle. It is thus easy to see that each half of the pipe is vibrating the same, and that the pitch produced by the open pipe is due to only half of the column. We should get this same pitch if a partition were placed across the middle and the upper half removed. This gives us a closed pipe only half as long for the same pitch.

FIG. 159 GLASS-WALLED ORGAN PIPE

If a hole is bored through the walls at any point in an organ pipe, the effect upon the pitch is very nearly the same as if the pipe were cut off at that point. It is by means of such holes, which may be opened or closed at will, that the length of the vibrating air column is controlled and notes of different pitch are sounded upon the fife, flute, and clarinet.

187. Overtones in Organ Pipes. In the previous experiment only a gentle blowing was needed to get the fundamental note of the pipe. If now the force of the blowing is slowly increased, there will be a fluttering effect, followed by a second clear note, the octave of the fundamental. Our membrane will show that there are nodes $\frac{1}{4}$ and $\frac{3}{4}$ way down. By proper regulation of the force we may produce a second overtone, in which the nodes are $\frac{1}{6}$, $\frac{1}{2}$, and $\frac{5}{6}$ way down. The pitch of this is the fifth above the octave. In the organ this regulation of overtones is called *voicing*.

Representing these conditions by Figure 160, in which the distance between the curved lines represents the degree of vibration of the air column at that part, we can say that the air column is vibrating in halves, fourths, sixths, eighths, etc. We can get from such an organ pipe successive overtones up to the fifth and sixth and even higher.

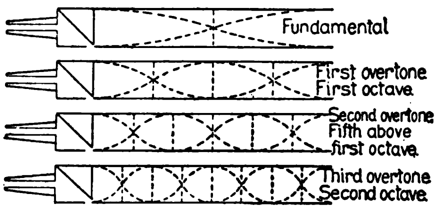


FIG. 160.—OVERTONES IN AN ORGAN PIPE

Summarizing, open pipes vibrate in halves when giving out their fundamental. They may also be made to vibrate in fourths, sixths, eighths, and so on, in even parts, giving octave, fifth above octave, second octave, third above second octave, fifth above second octave, third octave, and so on. As an example of open pipe instruments we have the fife, flute, and clarinet.

188. Pitch of Pipes. The pitch of any given pipe is determined by its length. Large long pipes emit low notes, while the short small pipes give out the high notes. This is true for both open and closed pipes. This may be demonstrated for the closed pipe by means of the sliding valve as in Figure 158.

As the length of the pipe is increased for lower pitch, the diameter must also be increased; for if the pipe is too narrow for its length, the air column is too easily broken into parts and overtones are more likely to sound than is the fundamental note.

In all cases of wind instruments the material and shape determine what overtones shall enter into the compound tone, which gives the instrument its characteristic quality.

189. Lip Instruments. In the trumpet or bugle, cornet, and trombone (Fig. 161), the puckered lips are placed across the mouthpiece. Air from the lungs passing through the slit thus formed sets the lips in vibration. The air column of the instrument resounds to these vibrations. The overtones are those of the *open* pipe. The length of the air column in the bugle is fixed. It is played by overtones only, beginning with

a b c

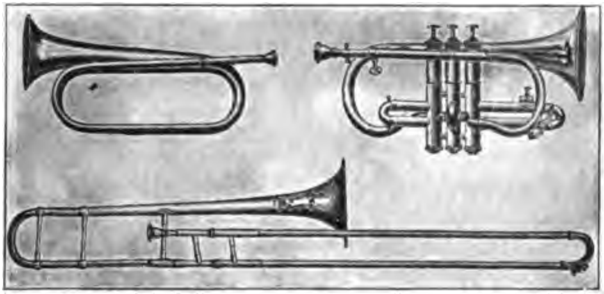


FIG. 161.—(*a*) BUGLE, (*b*) CORNET, (*c*) TROMBONE

the second. From it are obtained *sol′*, *do″*, *mi″*, *sol″*. In the cornet, there are loops in the tube. In these stops are inserted which are controlled by the fingers. In this manner the length of the vibrating air column may be changed by cutting off certain parts, and all the notes of the scale may thus be played. In the trombone, the length of the air column is regulated by a sliding part of the tube that may be moved back and forth, and the pitch is determined by this.

190. Vibrating Plates. Gongs and cymbals are cases of *plates* in vibration. The pitch of the notes they emit depends on their thickness and area. In bells we have curved plates. They never vibrate as a whole, but in four parts when they give their fundamental note. In vibrating, the edge of the bell

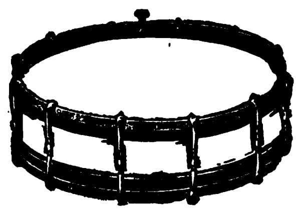
takes elliptical shapes alternately at right angles (Fig. 162), the points where the ellipses intersect, *a, b, c, d,* representing nodes. The presence of these may be shown by hanging pith balls so that they will touch the rim first at these points and then at points halfway between them.

FIG. 162.—BELL

Goblets may be set in vibration by rubbing a wet finger around the edges. By changing the volume of water in the goblet we may change the pitch of the resulting note. In this manner a series of goblets may be arranged to sound the scale and a tune may be played upon them.

191. Vibrating Membranes. When membranes are stretched tightly they may be set in vibration. In the tambourine (Fig. 163) we have the simplest form of this. In the drum there are two membranes with a confined body of air between. When one is struck the other membrane is set in vibration through the intervening air. Cords stretched over the second help to give the drum its characteristic rattling sound.

TAMBOURINE



DRUM

FIG. 163

A simple example of a vibrating membrane is found in the strip of rubber that is tightly stretched across the mouthpiece of toy balloons that are blown up by the air from the lungs;

also in the case of a piece of grass held tightly stretched between the thumbs. In both instances a disagreeable noise results when air is blown through the opening.

192. Phonograph. In the phonograph (Fig. 164) we have an instrument that reproduces sounds by mechanical means. This is brought about through a diaphragm placed over the small end of a tapering tube. Records of the sound waves

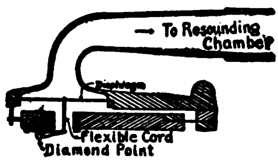


FIG. 164.—PHONOGRAPH WITH HORIZONTAL DIAPHRAGM

that are to be reproduced are made by concentrating the waves upon the diaphragm by means of a large horn attached to the tube. To this diaphragm is fastened a sharp pointed needle, which rests on a revolving cylinder or disc of wax. On this the vibrations of the needle make successive indentations when sound waves enter the horn and strike the diaphragm. The number and depth of the indentations depend upon the vibration frequency and intensity of these sound waves. Hard surfaced reproductions of this indented disc are made and sold as records. When such a record is placed under a similar needle and dia-

phragm, and is revolved, the point, as it moves up and down over the elevations and depressions on the disc, produces vibrations of the diaphragm. These and the sound waves that are set up, correspond to the original ones that caused the indentations.

In some types of phonographs the diaphragm is in a vertical position (Fig. 165), so that the effect upon the disc is sideways instead of up and down. The length of such a record is shorter

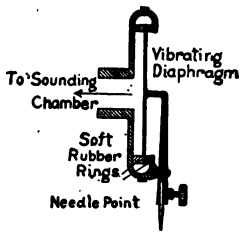


FIG. 165.—PHONOGRAPH WITH VERTICAL DIAPHRAGM

than that produced by the elevation and depression method, as the breadth of each line is greater.

193. Human Voice. This is the most wonderful musical instrument of all; for not only can the pitch of the note be changed at will, within certain limits, but the quality also can be changed. Here we find the vibrating substance to be a pair of membranes, called the *vocal cords,* which ordinarily lie loosely folded back against the walls of the windpipe near the opening of the pharynx (Fig. 166). When these are stretched tightly by the muscles to which they are attached, a narrow slit is left. As the air from the lungs passes through this slit the membranes are set in vibration. The rapidity of vibration depends upon the tension upon them. The throat, mouth, and nose cavities act as resonators in reënforcing these vibrations. The quality of the sound emitted depends upon the size and shape

of this combined cavity. The mouth cavity can be greatly modified by the altered position of tongue, cheeks, and palate (Fig. 167). In speaking, the letters used are divided into

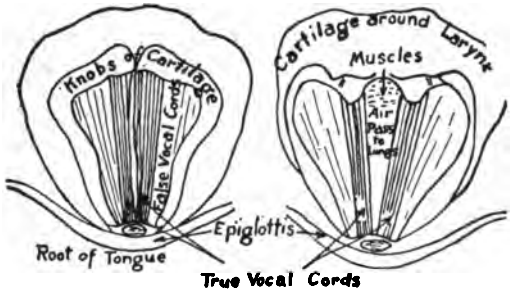


FIG. 166.—(*a*) CORDS STRETCHED FOR SPEAKING, (*b*) CORDS RELAXED FOR BREATHING ONLY

vowels and *consonants*. Vowels are formed by the combined effect of one or more simple notes added together. Consonants are called *labial, palatal,* or *guttural,* according as the lips, tongue, palate, or throat are used most in forming them. In all cases some vowel sound forms the basis of the letter. Speech is nothing more than a combination of vowel and consonant sounds, which when pronounced together form word sounds.

FIG. 167

Hoarseness is produced by a swelling of the inflamed cords and by a gathering of mucus in the opening between them. This interferes with their proper vibration.

194. Difference in Voices. The quality of the human voice is determined, as in the case of all other musical instruments, by the number of harmonics that are present. The more of these

that can be brought out, the fuller is the tone. All singers seek by long practice to acquire control over the vocal cords and shape of the mouth cavity, thereby attaining great range in pitch and ability to throw the sound.

The vocal cords in women and boys are naturally shorter than in men, with the result that women's voices are of higher pitch. This accounts for the soprano voices of boys, which deepen with mature years. Even among women on the one hand and among men on the other hand, there are variations in the natural length of the cords. Because of this we have soprano and alto voices among the women, and tenor, baritone, and bass among the men.

MEMBRANES SET IN VIBRATION BY SOUND WAVES

195. Telephone. In the phonograph, already described, sound waves coming to the diaphragm or thin disc set it in vibration. In the telephone transmitter also, which will be studied later, a disc is set in vibration by sound waves sent to it by the person speaking. This causes variations in the current passing through the wire, thereby making it possible to reproduce the sound in the receiver some distance away.

196. Human Ear. In the human ear (Fig. 168) is found the most perfect receiver of sound waves. It is through this that we are able to hear the many noises and musical sounds about us. Without it the sound waves would exist, but there would be no sensation of sound. This answers that question so often brought up as to whether there can be sound where there is no ear to receive the waves.

The ear is divided into three parts: the *external*, the *middle*,

and the *internal* ear. The external consists of the cartilagenous projection on the side of the head and a passageway about 1½ in. long into the bone on the side of the head. Its function is to catch as many sound waves as possible and direct them towards the *drum,* which is the dividing membrane between the outer and middle ear. To the drum is fastened, on the interior side, the *hammer,* the first of three bones joined together to form a

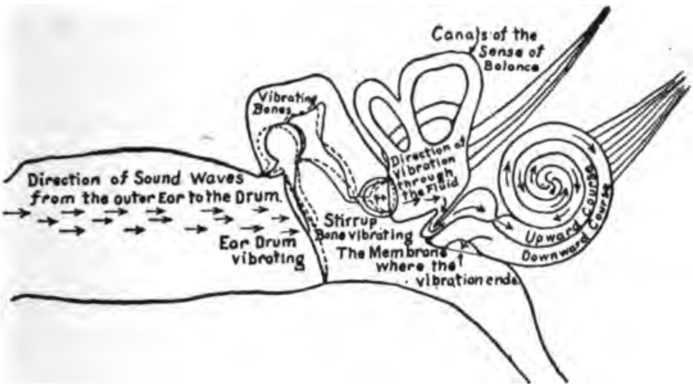


FIG. 168.—TRANSMISSION OF SOUND WAVES TO INNER EAR

connection between the drum and the inner ear. The other two bones in order are called the *anvil* and the *stirrup.* This last fits into a hole in the wall of the inner ear. In the inner ear is located the organ of hearing, consisting of about 3,000 minute fibers, different in length and each capable of vibrating in sympathy with a certain vibration frequency. They form one terminal of the auditory nerve, the other end of which is in the brain. The whole chamber is filled with a fluid. When the sound waves coming into the external ear strike the drum, they set it in vibration. The bones of the middle ear communicate this vibration to the fluid of the inner ear. Waves pass through

this, and each sensitive fiber picks from these the one to which it respectively corresponds and transmits the sensation to the brain. Here the combined effect of these sensations produces what we call a sound impression.

197. Deafness. From the above paragraph we see that in order to hear we must receive sound waves and transmit to the brain the effect of these upon the ear. Now if any one of the three parts of the ear, the drum, bones, or nerves, is out of order, deafness will result. If the nerve is affected the deafness is likely to be total. Sometimes the drum hardens and will not respond to the waves; sometimes the drum is destroyed. In this case the waves are transmitted in less degree to the inner ear and the deafness is not complete.

REËNFORCEMENT AND INTERFERENCE OF SOUND WAVES

198. Beats. We learned in Section 169 that some notes, when sounded together, produce a pleasant sensation, while others produce a throbbing effect that is disagreeable. This is due to the fact that the waves corresponding to different notes

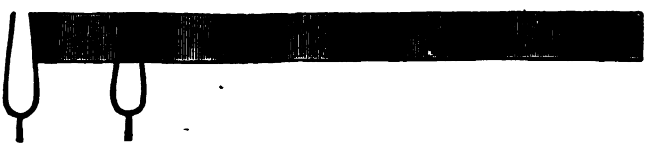


FIG. 169

sometimes act in conjunction and sometimes in opposition to each other. If two tuning forks of the same vibration frequency (Fig. 169) are set in vibration together, a sound of

increased intensity results. If, however, the vibration frequency of one is lessened by fastening a weight to one of the prongs (Fig. 170), the resulting sound rises and falls in volume. The nearer to the end the weight is fastened the more frequent the pulsating effect becomes, until it is so great as to be quite unpleasant. These successive changes are known as *beats*. They are due to the fact that the sound waves from the two forks alternately reënforce and interfere with each other. As long as rarefactions and condensations of the waves are coincident, the resulting sound is continuous and intensified. But if a rarefaction of one sound wave encounters a condensation of the other, one counteracts the other and silence results. In the intermediate stages we have results of varying intensity. Let us represent a succession of sound waves by the curved line (Fig. 171, I). That part above the horizontal represents the wave during rarefaction and the part below during condensation. The farther away the curved line is from the horizontal, the louder is the sound supposed to be. Two wave trains (Fig. 171, II), *A* and *B*, in which rarefaction and condensation are coincident will give the resultant wave *C*.

FIG. 170.—BEATS

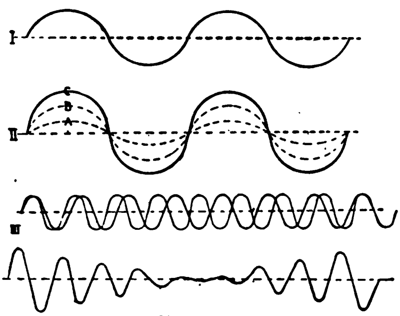


FIG. 171

Should the two wave trains differ by one wave per second (Fig. 171, III), there will be one time where rarefaction and condensation are opposite. The result of such combination will be an irregular wave condition, loudest at the beginning and the end and least in the middle of the second. This alternation of intensity produces the beat. Now if there is a difference of two waves per second, two beats per second will be the result, and so on. The number of the beats per second thus coincides with the difference in the vibration frequency of the sounding bodies. In the tuning of piano wires, where there is a set of two or three wires for a note, any difference in the vibration frequency produces beats. The tuner uses this principle as a means of determining whether the strings are under proper tension.

199. Harmony and Discord. When the number of beats per second is 32, the effect upon the ear is most disagreeable and *discord* results. As the number of beats per second is increased, the discordant effect dies away gradually, until, when there are 72 beats per second, the ear is unable to recognize them. A single note, when sounding, alternates so many times per second that the rise and fall between rarefaction and condensation is indistinguishable. Two successive notes, like c and d or b and c′, however, differ by 32 vibrations per second. These two notes therefore produce discord as before mentioned; c and e, c and g, differ by 64 and 128, respectively, so there is no discord.

In determining whether or not there will be harmony when notes are sounded together, we must consider not only whether the fundamentals are in harmony, but their overtones as well. The first overtone of c is c′ of 512 vibrations; the first overtone of e is e′ of 640 vibrations. These differ by 128 vibrations. In

the case of the second overtones of 768 and 960, respectively, again harmony results. The same condition is present in the case of the first and second overtones of c and g, g and c′. In writing music, composers must either consciously or unconsciously take into consideration the matter of beats in the grouping together of notes.

Questions

1. Why does the voice sound so differently when the nose is stopped up by a cold in the head?

2. What effect is produced when the speed of the phonograph disc is increased?

Review Questions on Sound

1. Explain the difference in pitch produced as a saw passes through a piece of wood.

2. Why does a bursting bag produce a noise?

3. Why can sounds be heard more clearly at night?

4. Why can sounds be heard farther on water than on land?

5. Explain the "swish" of a stick when it is moved rapidly through the air.

6. Why do tunnels and passageways sound "hollow"?

7. Why is the outer ear shaped as it is?

8. Why are chimes played singly?

9. What effect is produced by bowing a violin string in different places?

10. A stick the ends of which rest on glass tumblers may be broken in two without injury to the tumblers if it is struck sharply at the middle. Explain.

CHAPTER V

MAGNETISM AND ELECTRICITY

- Magnetism.
  - Magnets.
    - Natural and Artificial.
    - Poles.
  - Magnetic Field.
  - Magnetic Induction.
  - Theory of Magnetism.
- Static Electricity.
  - Unlike Charges.
  - Conductors and Insulators.
  - Difference in Potential.
- Cells.
  - Simple Voltaic Form.
  - Polarization.
- Magnetic Effects of Current.
  - Oersted's Experiment.
  - Electromagnet.
  - Electric Bell.
  - Wiring of Bell Circuits.
- Heating Effects of Current.
  - Fuses.
  - Electric Heaters.
  - Electric Lights.
    - Incandescent.
    - Arc.
    - Mercury Vapor.

Chemical Effects of Current.
  Electrolysis.
  Electroplating.
  Storage Cells.
Electromagnetic Induction.
  Faraday's Discovery.
  Dynamo and Motor.
Measurement of Electricity.
  Units, Volt, Ohm, Ampere.
  Ohm's Law.
  Electrical Power.
  Measuring Instruments.

MAGNETISM

200. **Natural Magnets.** In many parts of the world there is found a certain mineral that has the property of attracting to it particles of iron. Because it was first found near Magnesia, Asia Minor, the name *magnet* was given to the substance, its attractive power being called *magnetism*. Today we call the mineral *magnetite*. The ancients called it *Lodestone,* meaning "leading stone," because, as we shall see later, when it is suspended, it comes to rest with one end pointing always in the same direction, *north*.

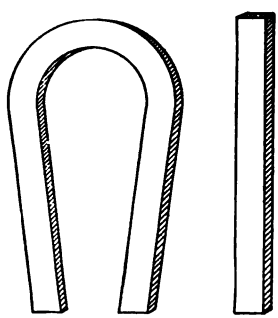


FIG. 172.—(*a*) HORSESHOE MAGNET, (*b*) STRAIGHT BAR MAGNET

201. **Artificial Magnets.** In the beginning of the study of magnetism, artificial magnets could be made only by means of natural ones. Steel was

the substance used for these, as it was found to remain magnetic longest. Today, through later discoveries, strong magnets are made more easily. These magnets are of different shapes, such as straight bar or horseshoe, and are called *permanent* magnets (Fig. 172).

202. Poles of Magnets. All magnets have a strong attraction for iron; they also attract nickel and cobalt. If a natural or an artificial magnet is rolled in iron filings, the latter cling most near two particular points, generally at opposite ends, with very few clinging to the parts between these spots (Fig. 173). These two places where the magnetic action is strongest are called *poles*.

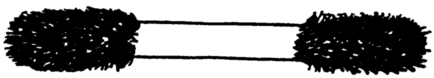


FIG. 173.—IRON FILINGS CLING TO THE POLES OF A MAGNET

203. Poles of a Magnet Are Unlike. If a magnet is suspended by a thread, as indicated in Figure 174, and left with no iron near, it always comes to rest in the same position, in a north and south direction. If turned out of this position it returns. Furthermore, if the north-seeking ends of two such suspended magnets are brought near each other, repulsion between these like ends results. This also happens when the two south ends are treated likewise. If, however, north and south ends are brought together, attraction results. We thus see that the two poles of a magnet are different, and that *like* poles *repel* and *unlike* poles *attract* each other. The north end is called the *north-seeking pole* and the south end is called the

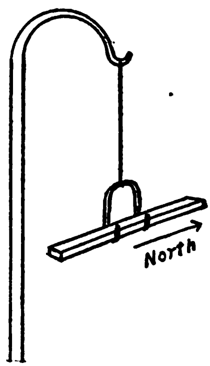


FIG. 174.—SUSPENDED MAGNET

south-seeking pole. Such a magnet balanced upon a needle point gives us the mariner's compass (Fig. 175) used so much for guidance on land and sea.

204. Magnetic Field—Lines of Magnetic Force. If a small compass needle is placed at various spots near a magnet, the direction in which the north-seeking end points will change. Near the south-seeking pole of the magnet it will point toward the magnet, Figure 176, I. Near the north-seeking pole it will point away, Figure 176, II. Midway between the two poles, provided it is not too far away from the magnet, it will point parallel with the magnet in the direction in which the south-seeking pole lies, Figure 176, III. If we put the compass in various spots, making an arrow to indicate the direction in which the needle points at those spots, we shall get a result something like Figure 177*a*. If now we take fine iron filings in place of a compass, sprinkling these upon a paper spread over the magnet, we shall get a result like Figure 177*b* when the paper is gently tapped. Here each iron filing is pointing in some particular direction. There seems to be a definite relation between the iron filings, as they are arranged in a series of curved lines which are farther apart as they lie farther from the magnet. These lines are called *lines of magnetic force,* and all the lines together, of which those in the drawing represent a small part, are called the *magnetic field* of the magnet. Those shown represent only

FIG. 175.—MAGNETIC COMPASS

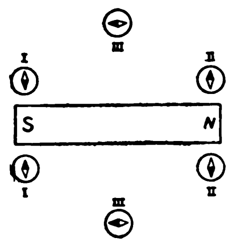


FIG. 176.—COMPASS NEEDLE NEAR MAGNET

the external part of the magnetic lines. Lines are supposed to pass through the magnet from pole to pole inside. They are not shown by the iron filings. An idealized drawing showing the external and internal *magnetic circuit* is found in Figure 177*c*.

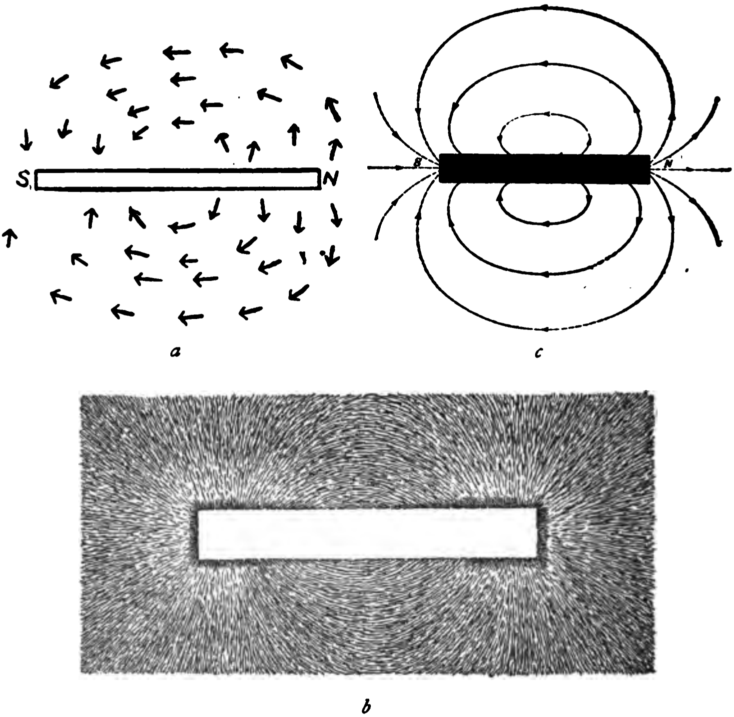
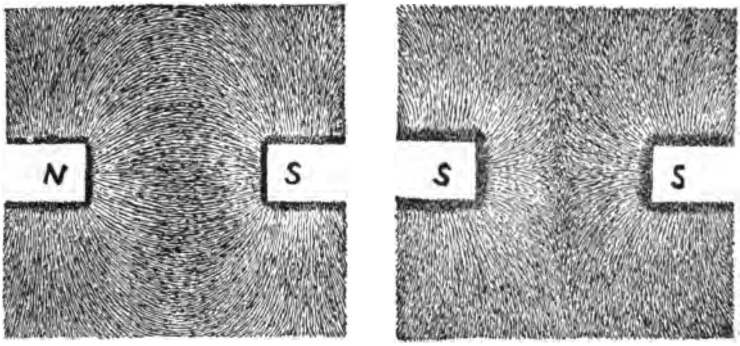


FIG. 177

Whenever iron filings or a small compass are placed in such a magnetic field, they are supposed to take such a position as to lie parallel with the lines of force at that particular spot where they are placed.

Figure 178*a* represents the magnetic field between two unlike poles when placed near each other. In this the lines pass



(*a*) MAGNETIC FIELD BETWEEN UNLIKE POLES

(*b*) MAGNETIC FIELD BETWEEN LIKE POLES

FIG. 178

across from pole to pole, thereby seeming to hold the magnets together in attraction. If two like poles are used, the result is like that shown in Figure 178*b*, where the lines do not pass across, but seem to meet half way, and then to pass sidewise, repelling, as it were. Figure 179 shows the effect when a horseshoe magnet is used.

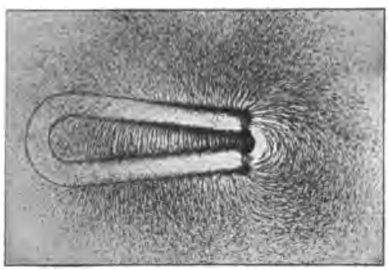


FIG. 179.—MAGNETIC FIELD BETWEEN POLES OF A HORSESHOE MAGNET

205. Permeability. A magnet can attract iron filings through most substances. If sheets of paper, glass, copper, aluminum, are placed between the magnet and the filings, the latter will be found adhering to the substance on the side away from the

magnet. The magnet will act even through glass and water to attract nails placed in a tumbler of water.

If a sheet of iron is placed near the magnet, filings are not attracted to the other side. The magnetic action seems to be obstructed by the iron. The lines of force, instead of passing *through* the iron, apparently go *into* it, resulting in an attraction of the sheet to the magnet. A study of various substances shows that magnetic lines pass through them in varying degrees. The tendency of the substance to concentrate the lines is called its *permeability*. A substance like bismuth tends to make the lines spread farther apart than they are in the air. Figure 180 shows the effect of placing a piece of iron called the *keeper* over the poles of a horseshoe magnet. This allows the external lines of force between the poles a much easier path through which to complete the magnetic circuit. The magnetic lines are supposed to point *away* from the north pole *outside*, and *toward* the north pole *inside* the magnet.

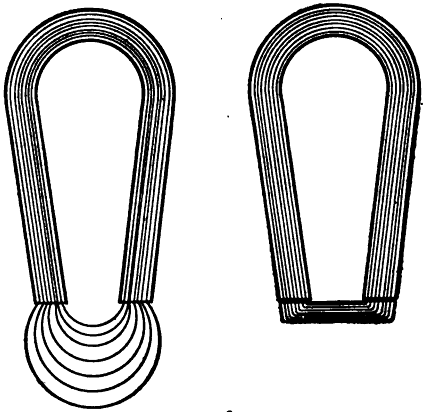


FIG. 180.—MAGNETIC LINES PASS MORE READILY THROUGH IRON THAN THROUGH AIR

206. Magnetic Induction. Many people are much troubled because, as they ride about in the trolley cars, their watches become magnetized and thus keep very irregular time. This is because there is considerable steel used in the mechanism of watches, and in the presence of a strong magnetic field, such

as is found about the motors of the trolley cars, this steel becomes magnetized.

That this can happen may be readily shown by bringing a soft iron nail near one end of a bar magnet (Fig. 181). Even though the nail does not touch the magnet, its lower end, when placed in iron filings and then lifted, will pick up some of the filings. If now the magnet is removed, the filings fall off. Furthermore, the lower end of the nail, if brought near a compass needle, will show the same polarity as the magnet pole that is acting upon the nail. The iron has thus been temporarily magnetized by the magnet. A hard steel needle treated in the same manner will show a similar effect upon the iron filings, though in less degree. The iron is very permeable or susceptible to magnetic influence, while steel is not so susceptible. To get a better effect upon the steel needle, we must stroke it with one pole of the magnet, from the middle to one end, and then with the other pole from the middle to the other end. The needle thus becomes a permanent magnet, as is evident when the larger magnet is removed.

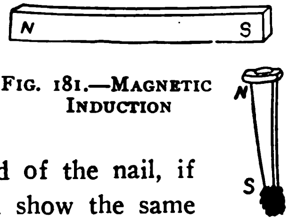


FIG. 181.—MAGNETIC INDUCTION


FIG. 182.—MAGNETIZED TACK HAMMER

We thus see that soft iron is easily magnetized, but does not stay so; while steel is not easily magnetized, but when once made so, it remains so. Iron has great *permeability*, while hard steel has great *retentivity*. The former is used only for *temporary* magnets, while the latter is best for *permanent* magnets. Steel blades of knives and scissors sometimes become mag-

netized. Tack hammer heads made of steel are often magnetized, and they thus hold a tack until it is driven into the wood (Fig. 182). The phenomenon of magnetic induction explains why iron filings are attracted to a magnet. Each filing becomes a small temporary magnet, with opposite pole next to that of the attracting magnet.

Small magnets, such as those in small compasses, frequently have their polarity reversed by being brought too rapidly under the influence of a strong magnet. Magnetic induction takes place so powerfully that the effect on the magnetic needle is the same as if the strong magnet were acting upon a piece of unmagnetized steel. Great care should be exercised in handling compasses to keep them away from such strong magnets, as a reversal of the polarity may mislead a person who depends upon a certain marked end of the compass as an indicator of north.

207. Residual Magnetism. Soft iron does not entirely cease to be magnetic when it is removed from the influence of a magnetic field. It still shows a certain amount of magnetic action. The amount retained depends upon the hardness and the purity of the iron used. This magnetism that is retained is called *residual* magnetism.

208. Earth a Magnet. The fact that a compass needle always points with the same pole north leads us to believe that it is arranging itself to point in the direction of certain lines of force, and that these lines of force are part of the field of a large magnet, the earth. This earth magnet has its poles in the northern part of North America, in Hudson Bay, and in the Antarctic Continent. The north magnetic pole and the north geographical pole are not identical, so that a compass will not point toward the north star on all parts of the earth. The north star is directly over the north geographical pole.

It is now plain to see why we call that end of the compass needle that points north, the north *seeking* pole. For if we call the north magnetic pole of the earth north, then the north-seeking pole of a magnet is really a south magnetic pole.

209. Theory of Magnetism. What magnetism is, no one knows. Neither do we know what electricity is. This does not prevent our using both, however, and discussing what they will do, for we have found them exceedingly helpful in our modern life.

If we break in two a long magnetized steel needle, we find that the two broken ends have poles where before, as one middle portion, they showed no indication of magnetism (Fig. 183). These two poles are opposite to each other and to the other ends of the magnets of which they are a part.

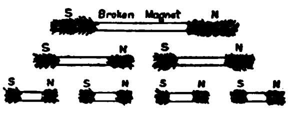


FIG. 183

If we further break these two, four magnets result. This process of breaking may be continued as long as the resulting magnet is long enough to be handled, two new magnets being formed for every one broken. From this result of breaking magnets the following generally accepted theory about magnets has resulted: all pieces of iron and steel, which are what we use for magnets, are made up of many particles, each a magnet. These particles, when the iron or steel is in an unmagnetized state, are all jumbled together,

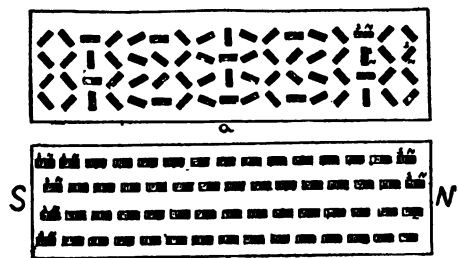


FIG. 184

pointing in all directions (Fig. 184*a*). When brought under the influence of a magnetic field of sufficient strength, these particles rearrange themselves so that the north poles all point in the same direction, just as do all the south poles (Fig. 184*b*). In this condition the poles are acting together to produce at one end a north pole for the whole bar, and at the other end a south pole. We can thus see why such a magnetized bar when broken will give us two magnets.

Questions

1. Will a small magnetized needle floating on a cork in a dish of water move northward or southward? Explain.

2. Two corks, each with a magnetized needle thrust through it vertically, are placed upon water. What will happen if the north pole of each is above the water? What will happen if the north pole of one and the south pole of the other are above?

3. What is the advantage of a horseshoe magnet over a straight bar one?

4. What is the object of the armature or keeper of the magnet? Of what should it be made?

5. How would a magnet point if taken to a spot above the north magnetic pole of the earth?

6. A magnet is placed at right angles to another so that its north-seeking pole is about half an inch from the middle of the other. Draw a diagram showing the arrangement of the magnetic lines around the two magnets.

7. Why must there be no iron near if a compass is to point accurately?

STATIC ELECTRICITY

210. Static Phenomena. It is quite common for children in a playful way to scuffle over the carpet on a cold day, and produce a spark by touching the knuckle to the gas pipe or to some one's cheek. A cat does not like to be stroked on such a day, as its fur crackles. Women combing their hair with a rubber comb "feel the electricity" resulting and hear the snapping. A piece of tissue paper placed against the wall and rubbed briskly with the hand remains in place after the hand has been removed. If the paper is removed by a corner and held near the wall it will quickly go back on to the wall again. If held near the hand or face it is strongly attracted to them. In all of the above instances we have a phenomenon known as *electrification,* resulting in every case from friction between two different objects. This is a very common phenomenon wherever there is such friction. Cold, dry air is, however, essential to success in getting very striking effects from the experiment.

For the study of this so-called *static electricity,* perhaps the simplest substance to use is tissue paper. A piece of glass and silk, or a piece of sealing wax and a cat's fur, will serve. If the substances of either of these two pairs are rubbed together, the glass or the sealing wax, when held near light substances, like bits of paper or the pith of the elder wood, will attract them. The rods are said to be *charged* with electricity and to give up some of this charge to the small particles.

211. Two Kinds of Charges. While the glass rod rubbed with the silk, and the sealing wax rubbed with the cat's fur, acted the same on the paper and the pith, they will not act the same on other charged rods of the same material. If a charged glass rod is suspended in a stirrup supported by a silk thread

(Fig. 185) and another charged glass rod is brought up, repulsion results. A similar result is obtained if two pieces of charged wax rods are used in the same manner. If, however, charged wax is brought up to the charged glass, attraction results. In the same way, if two pieces of charged tissue paper are suspended near each other repulsion results. If two pith

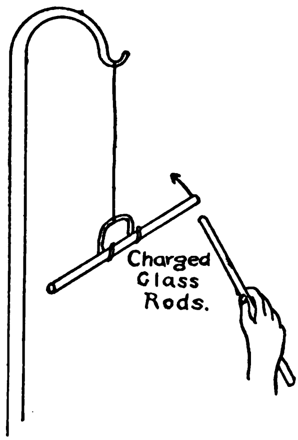


FIG. 185

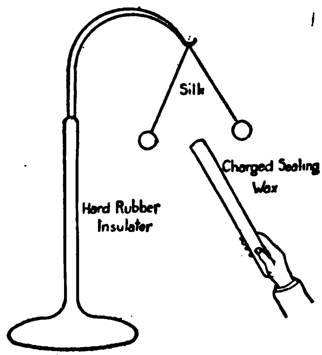


FIG. 186

balls suspended by silk threads (Fig. 186) are charged by being touched with either the charged wax or glass, they fly off from the rods and then stay some distance from each other. We are thus led to believe that the glass and the wax are charged differently when rubbed as described; also that *like charges repel* and *unlike charges attract* each other. The repulsion between like charges, and attraction between charged and uncharged objects, are most strikingly shown on cold, dry days when we try to fold a piece of tissue paper, over which we have first passed our hands in smoothing it out. The two halves

persist in flying apart, and both adhere most aggravatingly to the hand. This action is much more marked if the paper and the hand are cold.

The two kinds of charges are called positive (+) and negative (—). Different charged conditions may be obtained by rubbing different substances together. While the wax rubbed as above with the cat's fur was charged (—) and the glass rubbed with silk was (+), the cat's fur was (+) and the silk (—). As a result of experiments with different substances, the following table has been made out in which any article, when rubbed with any that comes after it, becomes charged (+). The other substance becomes charged (—).

Cat's fur,	Wood,
Flannel,	Metals,
Glass,	Hard rubber,
Cotton,	Sealing wax,
Silk,	Resin.

Thus glass becomes (+) charged when rubbed with silk, but (—) when rubbed with flannel or cat's fur.

212. **Conductors and Insulators.** If the hand is passed over the surface of a charged glass or wax rod, the charge disappears. Charged pith balls that are repelling each other, quickly come together if touched with the hand. The balls cannot readily be charged if suspended by a cotton thread, or if the silk thread is damp. Experiments in static electricity are hard to perform on damp days. We thus see that the electric charge can escape through some substances and not through others. These different substances are divided into *conductors* and *insulators* (poor conductors) of electricity. No substance is a perfect conductor or a perfect insulator. Among the best conductors are metals, salt solutions, acids, graphite; among

the poorest are rubber, dry gases, silk, wax, amber, shellac. Some substances lie between these two groups in their conducting power. Among these are cotton, linen, dry wood, paper, and the human body.

Just as long as there is an insulator between two differently charged bodies, there will be no loss of charge; but if they are connected by a conductor, immediately the charges will neutralize each other, electricity passing from + to — between them through the conductor. Sometimes the difference in charges becomes so great that the intervening medium, generally a gas, does not sufficiently resist the passage of the charge. In this case a spark passes through the gas. Such a condition is present in the case of lightning, when the clouds and certain parts of the earth become so differently charged that a big spark passes; generally from the cloud to the earth, but in some instances from the earth to the cloud, or even from one cloud to another. It is in the passage of this spark that houses and trees on the earth are struck.

That lightning is an electric discharge between clouds and the earth was proved conclusively by Benjamin Franklin, who flew a kite into the thunder clouds, using a hempen cord, near the lower end of which was fastened a silk cord, to be held in the hand. A metal key was hung from the end of the hempen cord a few inches above the ground. Sparks passing between the key and the ground showed the discharge between cloud and earth. The silk cord acted as an insulator, thus keeping the charge from passing through Franklin's body.

213. Difference in Potential—Direction of Flow. When two objects or parts of the same object are charged differently they are said to be of different *electrical potential.* When connected by a conductor, the electricity is said to flow from the

place of higher to that of lower potential. This was what happened in Franklin's experiment. The clouds and the earth were at different electrical potentials, and when the conductor, the hempen cord, furnished a path, the current of electricity passed through the cord.

Difference in electrical potential may be likened to difference in water level. Water flows only from a higher to a lower level. So electricity flows only from a higher to a lower *electrical* level (potential). There must be a means of transferring the electricity, just as there must be something to carry the water.

214. Electrical Flow between Charged Bodies Is Not Continuous. That we get only an instantaneous passage or flow of electricity through a conductor when two charged objects are connected is due to the fact that it is not possible to get very much electric charge on a body by frictional means. If it were possible to keep renewing the charge on the object as fast as it passes off, we should expect a continuous flow through the connecting wire or other conductor used. Such a means we have in the galvanic or voltaic cell and the dynamo, to be described later.

Questions

1. Is repulsion or attraction a sure sign of indicating the kind of charge? Explain.

2. State how you would proceed to determine the kind of charge on an object.

3. Explain why a brass rod held in the bare hand cannot be charged. What could be done to make it possible to charge it?

4. What kind of charge will an insulated brass rod have if rubbed with cat's fur?

5. A metal ball is suspended by a silk thread between two

objects, one charged positively, the other negatively. Explain what will happen.

6. Compare magnets with charged objects as to similarity and difference.

CELLS

215. Voltaic Cell. In the latter part of the eighteenth century, Galvani, an Italian physician, while experimenting with a pair of frog's legs, by chance hung upon an iron balustrade the copper wire by which the legs were suspended. As they were swinging back and forth, a sudden jerking took place whenever the lower end of the legs struck the iron balustrade. Galvani thus discovered how an electric current could be secured by other than frictional means, which was the only way known up to that time. Volta, another Italian, was the first to put this to a practical use, however, in the form of the *voltaic pile*. This consisted of a pile of copper and zinc discs alternating with each other, every pair being separated by a smaller disc of cardboard soaked with salt solution (Fig. 187). As a result, a sufficient difference in potential was secured between the top zinc and the bottom copper to produce many of the phenomena of static electricity; but better than that, it gave a continually renewed supply just as fast as the discharge took place. Thus came about the beginnings of our modern *Voltaic cell,* which consists of two different metals, preferably copper and zinc, placed each with one end in a dilute sulphuric acid solution. A

FIG. 187
VOLTAIC
PILE

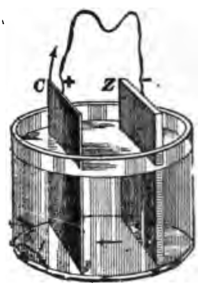


FIG. 188

difference in potential results, and if the strips, called *electrodes,* are connected outside by a conductor, a current flows continuously (Fig. 188). The reason that there is a difference in charged condition between the two metals, with resulting difference in potential, is that one metal is affected more by the liquid, and tends to dissolve more rapidly. Any two metals in the following list may be used, the one coming higher up on the list being the (—) electrode. The current flows to it through the wire from the other (+) electrode.

ELECTROCHEMICAL SERIES

Aluminum,	Copper,
Zinc,	Silver,
Iron,	Platinum,
Nickel,	Gold,
Tin,	Carbon.
Lead,	

216. Types of Cells. The commonest forms of cells in use are the wet sal-ammoniac cell, and the so-called "dry" cell. In the former (Fig. 189) the solution consists of sal-ammoniac (ammonium chloride) dissolved in water, the electrodes being zinc for the (—) and carbon for the (+). In every case the source of the electrical energy is the action of the solution on the electrodes. One is affected more than the other and gradually wastes away. In time it must be replaced.

FIG. 189.—SAL-AMMONIAC WET CELL

In the "dry" cell (Fig. 190) the same materials are used for the electrodes, the zinc forming the jar into which is packed the damp sal-ammoniac with the carbon placed in the center, surrounded by manganese dioxide. The top is sealed with pitch to prevent the evaporation of the water, which is essential to the electric action.

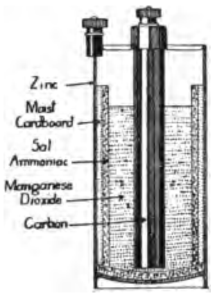


FIG. 190.—"DRY" CELL

The "dry" cell is more convenient than the other, but when once a hole has been eaten in the zinc covering, it soon really dries up and becomes useless.

In the wet cell, which has a glass jar, in which the liquid is placed, the solution may be replenished and the zinc renewed so that a longer use may be secured from it. The longer life more than makes up for the extra cost of this cell.

217. Battery. Sometimes, as we shall see later, two or more cells are used together in a circuit. Such a combination of cells is called a *battery*. The term battery is often applied incorrectly to a single cell.

218. Electric Circuit, Closed and Open. As long as the two electrodes of a cell are not connected, there will be no flow of electricity between them. They are, however, at a different potential, as can be shown by proper apparatus. If we connect them by a wire, a current flows through the wire outside and through the liquid inside the cell. The whole path through which the flow takes place is called the *electric circuit*. That part through the wire comprises the *external*, and that through the liquid forms the *internal circuit*. As long as the electrodes are connected so that the current flows, the circuit is a *closed*

one; but when the wires are disconnected anywhere, the circuit is an *open* one. The act of connecting the electrodes is called "closing" or "making" the circuit, and the act of disconnecting the wires is called "opening" or "breaking" the circuit.

219. Polarization. If we examine the surfaces of the zinc and the copper as they stand unconnected in the dilute sulphuric acid, no action will be apparent if the zinc is pure. When we connect them by a wire outside the liquid, however, a layer of gas forms over the surface of the copper and bubbles rise from it. These bubbles are hydrogen gas that has been set free by the chemical action taking place in the liquid. Let us use a very large copper plate and a piece of zinc wire (Fig. 191), connecting them through an instrument that indicates the current strength, called an *ammeter*. We shall find, after they have been immersed a few seconds, that the pointer, which moved considerably at first, will swing back towards the zero mark. This shows that the current has weakened. The phenomenon is called *polarization,* due to a weakening of the current caused by the collection of hydrogen bubbles on the copper plate. Polarization is largely prevented in sal-ammoniac and dry cells by surrounding the carbon, which corresponds to the copper of the voltaic cell, with an oxidizing agent in the form of manganese dioxide powder. The oxygen of this combines with the hydrogen to form water. In this way the collection of hydrogen gas on the carbon is diminished.

FIG. 191.—POLARIZATION

220. Local Action. If we bring the copper and zinc plates together outside the liquid while they are connected to the am-

meter, we find that no current passes through the ammeter. This is because there is an easier path for the current from copper to zinc, where they touch. Any easier path is called a *short circuit.* If we disconnect the zinc and copper from the meter, and make them touch inside, bubbles of hydrogen form on the copper, just as they do when the plates are connected outside. Commercial zinc, such as is used for cells in common use, is impure, containing considerable iron or carbon. Consequently, when such zinc is placed in the acid, a current flows between the zinc and the iron or carbon particles, just as between the zinc and copper when they touched inside the liquid, so that bubbles of hydrogen form, apparently on the zinc, but in reality on the carbon particles in the zinc (Fig. 192). This action is called *local action.* It is prevented by amalgamating the zinc, a process in which the zinc is coated with mercury, which covers up the iron or carbon particles without interfering with the action of the zinc.

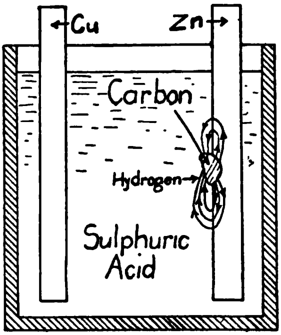


FIG. 192.—LOCAL ACTION

QUESTIONS

1. Why will there be no current if two strips of the same metal, such as copper, are placed in a solution of sulphuric acid and connected by a wire?

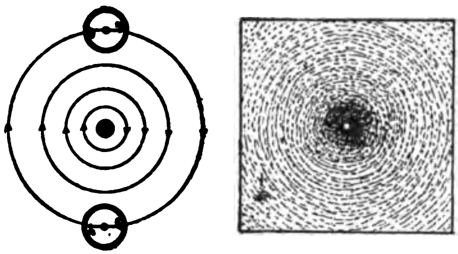
2. Why are zinc and carbon chosen for the plates in common cells?

3. What advantages has the dry cell over the wet cell?

4. Why are wires covered with an insulating material?

MAGNETIC EFFECTS OF THE ELECTRIC CURRENT

221. Oersted's Experiment. If a small compass is placed in various positions about a vertical wire through which a current of electricity is passing, there will be a change in the direction in which the needle points. If the wire is passing vertically through a card (Fig. 193*b*) and iron filings are sprinkled on this, they will take positions forming circles about the wire as a center.



a *b*

FIG. 193

This shows that there is a magnetic field around a current-carrying conductor. If the apparatus represented in Figure 194 is set up so that the wires lie in a north-south line with the magnetic needle placed between the wires, a current passing through the upper wire from south to north will make the north end of the needle swing toward the west. With the current reversed, the needle swings toward the east. A current from south to north in the lower wire produces the opposite effect from that of a south to north current in the upper wire, the needle swinging toward the east. Likewise an opposite effect is produced when

FIG. 194

the current is north to south, the needle swinging toward the west. An increased current produces a greater effect in all cases. Inasmuch as compass needles tend to point the same way as the magnetic lines of the field in which they are placed, the

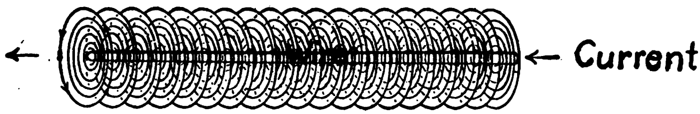


FIG. 195.—MAGNETIC WHORL

conclusion from the above effects is that a magnetic field about a current-carrying conductor acts in the opposite direction on opposite sides of the wire. It is in the form of a whorl or bundle of concentric magnetic circles. These are acting in a right-handed, corkscrew fashion when viewed along the wire in the direction in which the current flows (Fig. 195).

222. Rule for Determining the Direction of the Magnetic Effect. If the *right* hand is placed upon the *opposite* side of the wire from the compass needle, with the palm toward the wire and the fingers pointing in the direction in which the current flows, the thumb will be on that side of the wire to which the north end of the compass needle swings (Fig. 196).

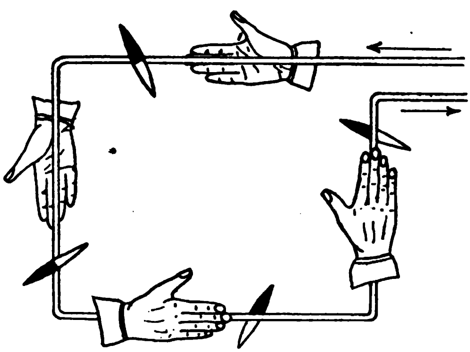


FIG. 196.—THUMB RULE FOR CURRENT IN A WIRE

223. Electromagnet. If a current flows from south to north in the upper wire of Figure 194, and from north to south

in the lower wire, the effect on the needle is greatly increased, as shown by the greater swing toward the west. Thus if a current flows through several turns of wire (Fig. 197), the intensity of the field will be multiplied by this greater number, each separate turn furnishing its additional magnetic field. If each end of the coil is tested with a compass needle, one of them will be found to attract the north and the other the south end of the magnet. We thus have an effect similar to a magnet as a result of a current of electricity, even though no iron is present. Such a coil with the current passing through it is called a *solenoid*. If a piece of soft iron is placed in the coil, the effect upon the compass needle is greatly intensified, and the result is a magnet much stronger than any natural or permanent one. Such an arrangement, consisting of a solenoid with an iron bar or *core,* is called an *electromagnet*. Other than the fact that it is much stronger, this magnet is similar in its action to any natural or permanent magnet, having unlike poles at its ends. Such magnets may be straight or horseshoe (Fig. 198). The strength of an electromagnet is determined by the number of turns there are in the coil and by the strength of the current flowing through the coil.

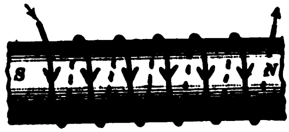


FIG. 197.—SOLENOID

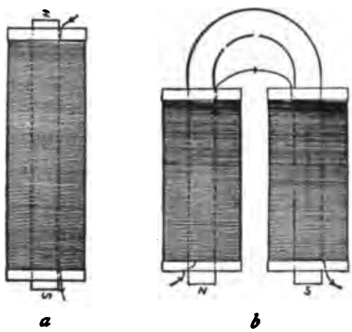


FIG. 198.—(*a*) STRAIGHT BAR ELECTROMAGNET, (*b*) HORSESHOE ELECTROMAGNET

224. How to Tell the Polarity of an Electromagnet. If the coil is grasped in the *right* hand, with the fingers pointing the way the current is flowing, the end where the thumb lies will be the north pole and the other the south pole (Fig. 199). Another way is to look at the magnet endwise. If the current

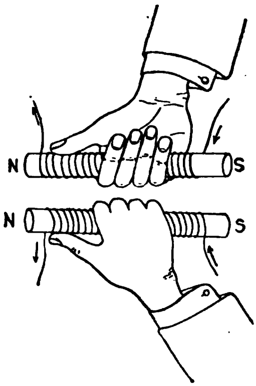


FIG. 199.—THUMB RULE FOR ELECTROMAGNET

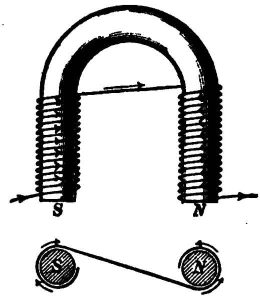


FIG. 200.—CLOCK RULE

is flowing through the coils in a right-handed direction, like the motion of the hands of a clock, that pole looked at is south; otherwise it is north (Fig. 200).

225. Use of Electromagnets. The discovery of the principle of the electromagnet by Oersted revolutionized modern electricity; for it has given us, among other things, the electric bell, telegraph, telephone, dynamo, and motor.

226. Electromagnet for Surgical Purposes. In former years the only means of removing pieces of iron or steel that sometimes lodged in the eyes of persons engaged in the iron trades was the knife. Nowadays electromagnets are made of such shape and strength that it is a simple thing to draw out

a piece of steel through the hole made by the particle when it entered the eye or other part of the body (Fig. 201).

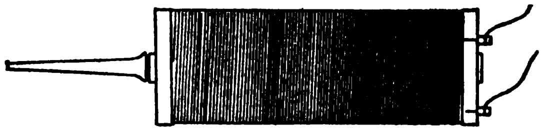


FIG. 201.—MEDICAL ELECTROMAGNET

227. Electric Bell. In the electric bell we have perhaps the commonest use to which the electromagnet has been put. There are two kinds of bells; one in which the bell rings but once when the current flows; and the other, called the vibrating or intermittent bell, which keeps ringing as long as the push button is pressed.

In the single stroke bell (Fig. 202*a*), when the button *B* is pushed down, thus closing the circuit between the battery and the bell, the current continues to flow through the electromagnet just as long as the button is so held, and the iron bar or armature *A* is pulled over and held against the magnet. The clapper strikes the bell once only, when the bar is first pulled over. Only when the push button is released can the clapper go back. Then the spring *S* pulls it back, because the magnetic attraction has ceased.

In the vibrating bell (Fig. 202*b*), even though the push button is kept down, there is an arrangement in the bell itself whereby the circuit is broken. At the first contact of the push button *B*, which completes the circuit, a current flows through the coils, producing a magnetic effect that attracts the soft iron bar *A* and causes the clapper to strike the bell. This action, however, at the same time breaks the circuit at *C*, and the attraction between the magnet and the bar ceases. The spring *S* makes

the bar go back, when contact at *C* again sets up a current in the coils and the striking process is repeated. This intermittent action goes on as long as the circuit is completed at the push button.

In the iron framed bell, the iron base takes the place of the

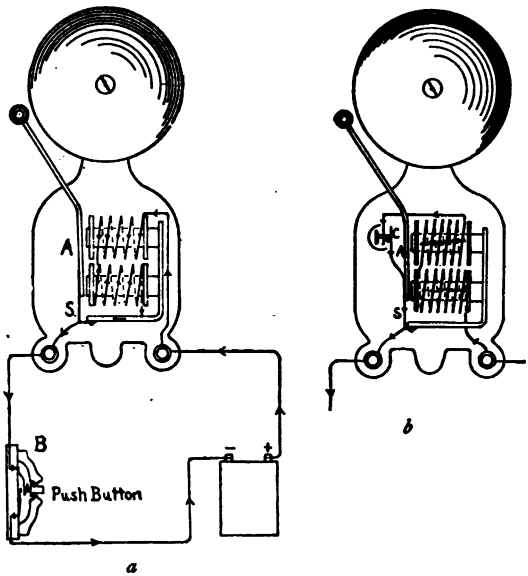


FIG. 202.—(*a*) SINGLE STROKE BELL, (*b*) VIBRATING BELL

wire from the clapper to the binding post. The binding post from which the wire to the coils starts and the support for the contact screw *C* are both insulated from the iron base.

Fire alarm bells are sounded by means of a hammer operated by clockwork. The clock works are set in motion by an electro-magnet, which, when the current flows, releases a catch.

228. Wiring of Bell Circuits in Houses. The commonest use of an electric bell in a house is for signaling purposes at

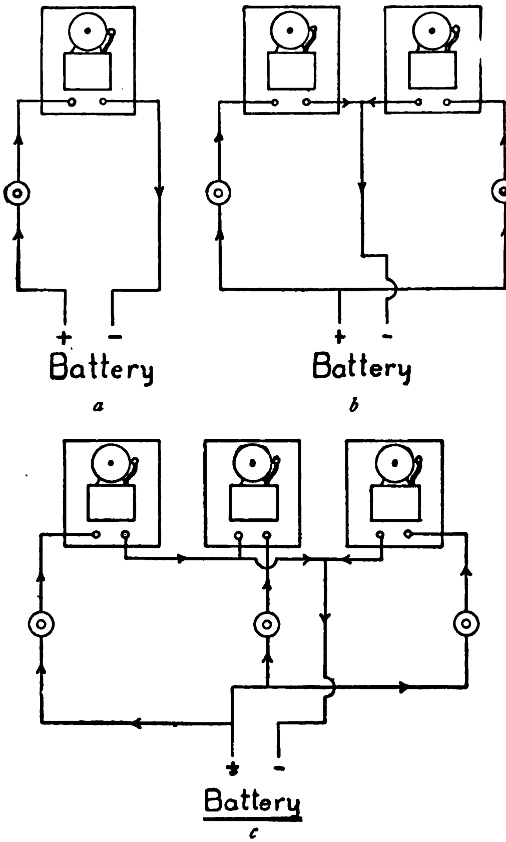


FIG. 203

the front and back doors and in the dining room, the bells being located in the kitchen, and the batteries in the cellar. Figure 203*a* shows the arrangement of bell, battery, push

button, and wires for a single bell circuit. In the case of two bells, front and back door, Figure 203*b* shows the most economical arrangement of wires. Here one wire from the bells to the battery suffices for both bells. Figure 203*c* shows the wiring with dining-room bell added.

Sometimes one push button is used to ring two bells at the same time, one upstairs and the other downstairs. Figure 204*a* shows such an arrangement.

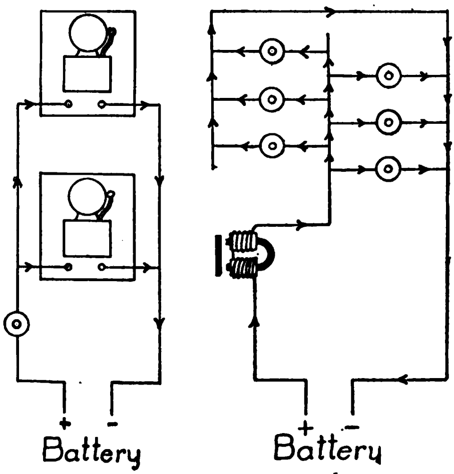


FIG. 204

In apartment houses, control over the door latch is secured through an electromagnet operated by means of push buttons, one in each apartment. When any button is pushed, thereby closing the circuit, an electromagnet acts to release the catch on the door frame. The action is like that of the single stroke bell, with several push buttons on the circuit (Fig. 204*b*).

229. Causes of Failure of Bells to Ring. In most cases, failure of bells to ring is due to weak cells which need either a new zinc or a new solution. If dry cells are used, new ones must be bought.

If the trouble is not due to the cells, there is probably trouble with the contact at the push button or on the vibrator of the

bell. The least probable cause of trouble is a break in the wire somewhere, unless it be at the binding posts of the bell, or of the cells, or at the push-button screws.

Questions

1. What would be the effect if equal currents of electricity were passed in the same direction through two parallel wires, one above and one below a compass needle?

2. A strong current of electricity flows through a wire from east to west. How would a small compass needle point if placed below this wire?

3. Two coils are suspended end to end, parallel to each other. What would be the effect if a strong current passed through each coil, flowing in the same direction in both? What would be the effect if the current passed in opposite directions in the two coils?

4. A small coil is suspended between the poles of a strong permanent magnet. What will be the result if a current is passed through the coil?

5. What is the difference between a solenoid and an electromagnet?

6. Why would not a wooden core do just as well as an iron one in an electromagnet?

7. What would be the result if the current flowed in the same direction in the two coils of a U-shaped electromagnet?

8. What is the objection to the use of steel for the core of an electromagnet?

9. Why will not an electric bell ring when the button is not being pushed?

10. What makes the clapper move over and strike the bell?

11. Explain the intermittent action of a vibrating electric bell.

12. Describe the steps you would take to locate the trouble if a doorbell failed to ring.

13. Draw a diagram showing how one push button will ring three bells.

14. Draw a diagram showing how with the same battery two bells may be rung by one push button, while a third bell only may be rung by a second push button.

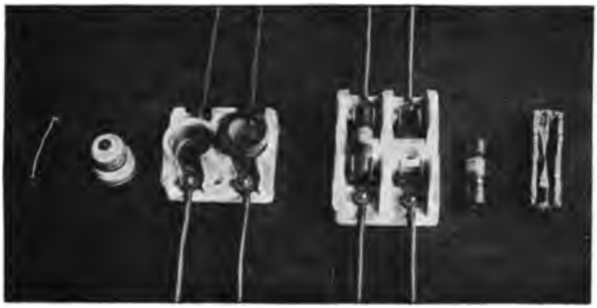
15. An electromagnet looked at endwise presents a north pole. In which direction, clockwise or counter-clockwise, is the current flowing through the coil?

HEATING EFFECT OF THE ELECTRIC CURRENT

230. Heating Phenomenon—Fuses. Whenever an electric current passes through a wire, the wire becomes heated. The degree of heat depends upon the strength of the current, the size of the wire, and the composition of the wire. This heating effect serves many useful purposes, but it must be kept under control, as many fires have resulted from overheated wires.

There is a limit to the amount of current that it is safe to send through a wire; for if it becomes great enough, the wire becomes so hot that it first glows, then becomes white hot, and finally melts. For this reason *fuses* are used on circuits. These are made of metal that melts at a low temperature, so that if the current becomes too strong the heat melts them and thus breaks the circuit before the wire parts become overheated. Three types of fuses (Fig. 205), called the *open wire link,* the *screw inclosed,* and the *cartridge,* are in general use. The last two are the ones used in houses, as the danger from fire at the

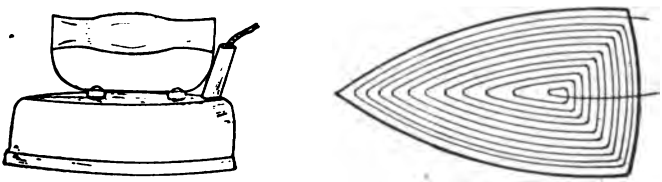
instant the fuse melts is prevented by the fireproof casing in which the fusible metal is placed. Figure 205*d* shows a cartridge fuse cut open to expose the fuse metal.



a *b* *c* *d*

FIG. 205.—(*a*) LINK FUSE, (*b*) SCREW INCLOSED FUSE AND BASE, (*c*) CARTRIDGE FUSE AND BASE

231. Electric Heaters. Electric cars are heated by an electric current flowing through coils of wire under the seats. The electric flatiron (Fig. 206) consists of a coil or a grid of wire



a *b*

FIG. 206.—(*a*) ELECTRIC FLATIRON, (*b*) WIRE GRID

placed inside a hollow iron casing. The heat is radiated to the casing, that can thus be kept at a given constant temperature. Instantaneous electric water heaters (Fig. 207*a*) consist of a coil in a metal casing, which gives up its heat to the water in which it is placed. Electric warming pads (Fig. 207*b*) have

wire enmeshed in asbestos sewed into the material of which the pad is made. In the electric toaster (Fig. 207*c*) heat is radiated from coils that are fastened in the framework.

a *b* *c*

FIG. 207.—(*a*) ELECTRIC WATER HEATER, (*b*) ELECTRIC WARMING PAD, (*c*) ELECTRIC TOASTER

232. Incandescent Electric Light. This light (Fig. 208) consists of a glass globe from which the air has been removed and inside of which there is a filament of carbon, tungsten, or tantalum; the two ends of this filament are connected to the outside wires through pieces of platinum sealed into the glass walls of the bulb (see Section 10). When the electric current is turned on, the filament becomes heated to incandescence. The size and length of the filament affect the current strength, and therefore the amount of light obtained. We thus get lights of different brightness. The air must be removed from the bulb, because the filament would oxidize and soon be destroyed if any oxygen were present. The two platinum wire ends are connected to a brass disc and ring respectively. These are insulated from each other. The whole lamp screws into a socket in which there is

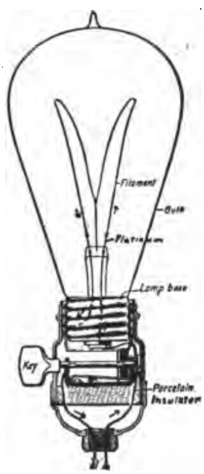
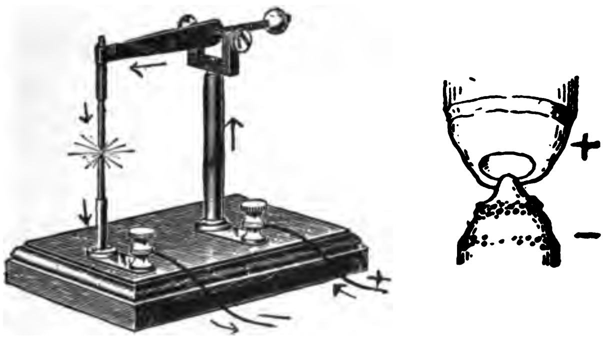


FIG. 208.—INCANDESCENT ELECTRIC LAMP

a corresponding ring and disc, to which the ends of the two service wires are fastened. Thus the current flows when the switch completing the house circuit is turned on. The advantage of such a means of lighting lies in the ease with which the light can be turned on or off.

233. Arc Light. The arc light makes our streets nearly as brilliant at night as in the daytime. This is brought about by the fact that incandescent particles of carbon, when heated to a white heat by the electric current, will jump across a gap



a *b*

FIG. 209.—SIMPLE ARC LIGHT

between the ends of two carbon rods, and produce what is called the *electric arc*. Such an arc is dazzling, and produces a light most nearly approaching that of sunlight both in brilliancy and color. Figure 209*a* represents such an arc light in its *simplest form*. The carbon ends are first brought together to complete the circuit. When they are pulled apart the current continues to flow across the intervening space, forming the arc. The carbons can be pulled some distance apart before the arc "breaks" and the current ceases to flow. Naturally the (+) carbon wears away and the (—) carbon tends to grow. The

result is that the (+) carbon becomes hollowed, forming a crater, and the (—) becomes pointed (Fig. 209*b*). If the carbons are exposed to the oxygen of the air while burning, there is a gradual wearing away of both, due to the consumed oxidized carbon, and the carbons must be renewed from time to time. As the carbons wear away, the ends forming the arc must occasionally be brought nearer together, so that the gap will not become too great for the arc to be maintained. In projection lanterns and in other pieces of apparatus, where the light is used for a short time, this can be done by hand; but on street lamps, where the lights run for nearly all the night, the "feeding" of the carbons is done automatically by a system of electromagnets above the carbons (Fig. 210).

FIG 210.—AUTOMATIC FEED ARC LAMP, OPEN TYPE

234. Inclosed Arc Lamps. The latest of street arc lights are of the inclosed type, in which the arc is inclosed in a nearly air-tight glass globe with an opening at the top. In such a case the carbons last much longer, as there is very little opportunity for the oxygen of the air to get to the arc.

235. Mercury Vapor Lamp. In this form of lamp, vapor of mercury is made the conductor between the two terminals. It consists of a long glass tube from which the air has been removed (Fig. 211). Through each end a platinum wire is sealed. The lower end consists of a receptacle for mercury. The (+) terminal of the supply is attached to the upper end, and the (—) terminal to the end containing the mercury. When the tube is brought to a horizontal position a thin stream of

mercury flows to the other end, thereby completing the circuit just as the carbons of the arc light complete the circuit when they are brought together. If the tube is tilted back to its slanting position, an arc of heated mercury vapor forms throughout the tube as the mercury flows back. This arc produces a greenish light that lacks red waves. It is a very penetrating light and brings out shape and outline clearly. It is a cheap light and is therefore often used where the lack of red waves is not objectionable.

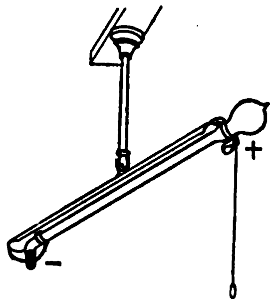


FIG. 211.—MERCURY VAPOR LAMP

QUESTIONS

1. What is the reason that inclosed fuses are better in houses? Why are those of the open type used at all?

2. Explain why the (+) carbon in the arc light becomes hollow while the (—) becomes pointed.

3. What is the object of inclosing the carbons in the globes of some arc lights?

4. What makes the inside of an incandescent light bulb become darkened?

5. Why does the fuse on a circuit melt before the copper wire can?

CHEMICAL EFFECT OF THE ELECTRIC CURRENT

236. Electrolysis. A glance at the table of electric conductors and insulators will show that water is neither a good conductor nor a good insulator. In fact, it stands between these two extremes. Pure water conducts electricity very slightly. If, however, we put some soluble substance like copper sulphate, silver nitrate, or lead acetate into the water, a good conductor results. Such solutions are called *electrolytes,* of which there are many kinds.

When an electric current is sent through a dilute copper sulphate solution, a very remarkable phenomenon takes place. The name *electrodes* is given to the wires by which the current passes into and out of the *electrolyte*. The one by which the current enters is called the *anode,* and the one by which it leaves is called the *cathode*. If these electrodes are made of platinum strips, in the case of the copper sulphate solution, the cathode gradually becomes coated with copper, and from the anode bubbles of gas arise. If the current is now reversed, the copper will disappear from the electrode that is now the anode, and copper will deposit upon the new cathode. If a lead solution is used, lead deposits upon the cathode; with silver, gold, and nickel solutions, silver, gold, and nickel respectively will deposit upon the cathode. If hydrogen sulphate (sulphuric acid) solution is used, hydrogen gas forms at the cathode and oxygen gas at the anode. This is one of our means of determining that water is composed of hydrogen and oxygen. In all cases the metal travels through the electrolyte in the same direction as the current.

237. Electroplating. By means of the above process of electrolysis of solutions of metals, we have a method of depositing metals upon other metallic surfaces. Silver, gold, and nickel plating are done in this manner. The object to be plated is used as the cathode in a solution of the metal to be deposited, and a bar of the solution metal is used as the anode (Fig. 212). The purpose of this anode is to keep the solution supplied with fresh metal just as fast as it is deposited from the solution upon the cathode. The current is allowed to flow until the desired thickness of deposit is secured, when it is turned off and the plated object is removed and polished.

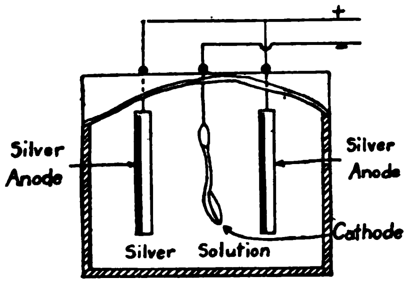


FIG. 212.—ELECTROPLATING

The process of electroplating has made it possible for people to have plated silver or gold when solid silver or gold would be too expensive. Such plated ware, whether of gold or silver, lasts many years before the metal deposit wears through.

238. Electrotyping. Books are nowadays generally printed from electrotypes, which are copper-faced reproductions of the type as set up by the typesetters. The object of this is twofold: (1) to secure a harder surfaced type which will last longer, and (2) to avoid the expense of buying a new set of type for each new book published. All large publishers have a set of electrotypes of every book on their list, so that at any time a new edition may be printed without the expense of resetting the type.

In the production of an electrotype, a wax impression

(Fig. 213) is made of the page of type as set up. To make the surface of this wax mold a conductor of electricity, finely powdered graphite is brushed onto every part. This coated wax is then suspended as the cathode in a copper sulphate solution. When the current has flowed long enough to make the copper deposit of just sufficient thickness to be stiff, the form is removed

FIG. 213.— REPRODUCTION OF WAX IMPRESSION FROM WHICH THE ELECTROTYPE FOR PAGE 231 WAS MADE

FIG. 214.— REPRODUCTION OF ELECTROTYPE USED FOR PRINTING PAGE 231, REDUCED TO TWO-FIFTHS

and hot water is poured over the front. This melts the wax directly underneath and the copper strip is easily removed. Over the back of this molten metal is poured, which on solidifying gives the copper sufficient rigidity to stand the pressure of printing. As a result we get an exact duplicate of the original type form, with copper facing (Fig. 214).

239. Storage Cell. Of late years much attention has been paid to the storage cell because of its extensive use in the electric automobile, and in electric light and electric car power houses. In the household we find it of great use to the physician and surgeon. In the first instance, a light-weight cell was needed. The genius of Thomas Edison solved this problem, giving us today a storage cell that is very economical. In the case of power houses, the storage cells are used for reservoirs in which to store

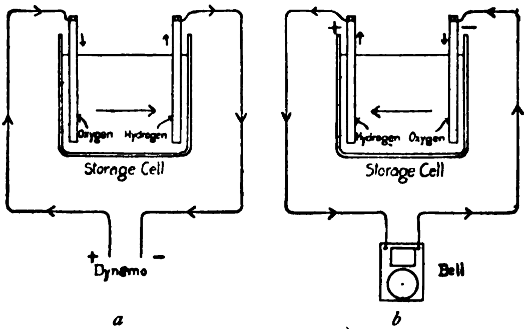


FIG. 215.—(*a*) STORAGE CELL CHARGING, (*b*) STORAGE CELL DISCHARGING

the excess electricity generated by dynamos during the hours of the day when little electricity is being used. In this way there is an extra supply to draw upon during rush hours, and the dynamos can thus be run evenly all day and night.

In the storage type of cell we have simply what the name implies, a storehouse for electricity, not a source. Before it can be of any use the storage cell must be stored or charged with electricity, just as a coal bin must be filled with coal. In the process of storing, the electrodes, as used in this electrolytic cell, are changed to become so different that when the charging current is removed and the electrodes are connected

through a bell, light, motor, or other piece of electrical apparatus, the cell acts like a source of electricity. A current passes out of it in the opposite direction from which the current passed through it when it was charged (Fig. 215). Just as soon as the cell has given out what was put into it, it will cease to act further.

It must be borne in mind that electricity can pass through an electrolytic cell and change the character of the cell, performing electrical work in so doing, just as a man may go up three flights of stairs, carrying something up the second flight only. He does work in climbing all three flights, but does most work in climbing the second flight, because on this he meets the most opposition. We must not get the idea that the electricity goes into the cell only and stops there.

240. Lead Storage Cell. In the common lead type of storage cell the two plates are made of lead framework, into which a paste of lead oxide has been forced (Fig. 216). One of these is made the cathode and the other the anode, in a solution of sulphuric acid. During the process of "charging," the hydrogen collecting on the cathode reduces the oxide to spongy lead, while the anode is further oxidized by the oxygen which collects upon it. There thus results a considerable difference in potential between the two plates. When they are connected through the outside conductor the lead oxide becomes the + electrode and the lead becomes the — electrode. On discharge, the positive lead oxide is reduced and the negative lead is oxidized, which is the reverse of what occurred during the charging process.

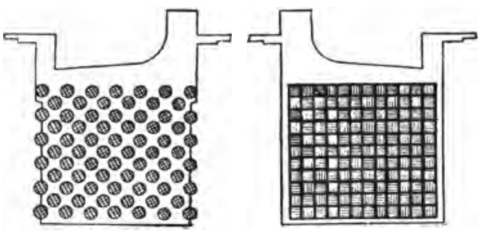
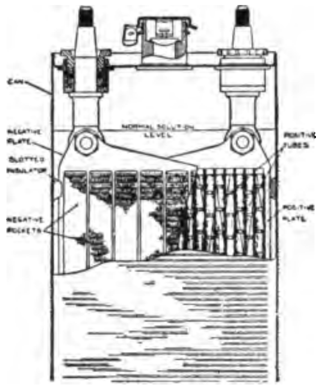


FIG. 216.—PLATES OF LEAD STORAGE CELL

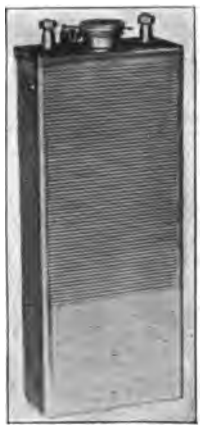
241. Edison Storage Cell. In this type of cell, which is displacing the heavy lead type, wherever light weight is desired, the plates are of nickel hydrate and iron oxide respectively (Fig. 217). The solution is of potassium hydrate in water. In

a



c

FIG. 217.—EDISON STORAGE CELL, (*a*) PLATES, (*b*) CASE, (*c*) PLATES IN POSITION



b

the process of charging, the nickel hydrate is the anode and the iron oxide the cathode. As a result of this charging process, hydrogen forming on the iron oxide reduces it, while oxygen forming on the nickel hydrate oxidizes it. When discharge takes place, the reduced iron oxide is the — electrode, and the nickel oxide is the + electrode. During discharge the iron becomes oxidized and the nickel oxide becomes reduced.

Questions

1. What would be the result if a platinum plate instead of a copper bar were used as the anode in copper plating? (Platinum does not go into solution.)

2. What would be the result if graphite were not spread over the entire surface of the wax impression upon which the copper is deposited in making an electrotype?

3. Compare the direction of the flow of electricity through a storage cell when it is being charged and when it discharges.

4. Compare the charging of a storage cell with the storing of water in a tank above a house.

5. Define anode, cathode, electrolyte.

6. Describe how you would gold-plate the bowl of a spoon.

7. How by means of a copper solution could you tell which wire of a circuit is + and which —?

8. What is meant by quadruple silver plate?

9. What is Sheffield plate? (See Encyclopædia.)

ELECTROMAGNETIC INDUCTION

242. Faraday's Discovery. With the discovery made by Michael Faraday, about the middle of the nineteenth century, that a current of electricity could be set up in a wire by moving the wire in a magnetic field, there resulted a more important advance in our knowledge of electricity than that furnished by Volta in the discovery of the electric cell. It was Faraday's experiment and interpretation that led up to the later discovery of the modern dynamo, by which electricity has been furnished in sufficient quantity to give us our incandescent and arc lights, as well as to run the motors of our sewing machines, trolley cars,

and locomotives. This would never have been possible with cells alone.

243. Electric Current Produced in a Wire by Moving a Coil in a Magnetic Field. If a coil of wire (Fig. 218), with its two ends connected to a milliammeter,[1] is moved up to the north pole of a permanent magnet, a current will flow through the coil and will be indicated by the swing of the milliammeter needle. The current ceases to flow when the motion stops. If

FIG. 218.—CURRENT INDUCED BY MEANS OF A PERMANENT MAGNET

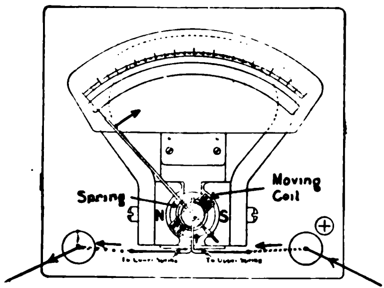


FIG. 219.—MILLIAMMETER

the coil is pulled away from the magnet, a current in the opposite direction will be set up, the milliammeter needle swinging to the other side. The milliammeter, often called a galvanometer, consists of a coil of wire with a pointer fastened to it, and suspended between the poles of a permanent magnet. When a current flows through the coil the magnetic field set up in it makes it act like a compass. This is acted upon by the powerful field of the magnet, and the coil turns just as if it were a compass needle, so as to cause its lines of force to lie in the same direction as those in the field of the magnet (Fig. 219).

[1] Such a coil, with its ends connected, is called a closed coil as contrasted with an open one, with its ends unconnected.

If the coil is brought up to the south pole of the magnet, a similar effect takes place, only the needle swings the *same* way on bringing *up* the coil as it did upon *removing* it from the *north* pole of the magnet. If now the magnet is moved into and out of the coil, exactly the same effects are produced as when the coil was moved, the direction of the flow depending upon whether the motion is up to or away from the coil and upon which pole of the magnet is used.

244. Effect Produced by Using a Solenoid instead of a Permanent Magnet. If (Fig. 220) a solenoid is used instead of the magnet and the above mentioned motions are repeated, exactly similar effects as to current set up in the closed coil are the result. It is immaterial which coil is moved. Furthermore, if an iron core is inserted, making an electromagnet, the effect is intensified.

FIG. 220.—CURRENT INDUCED BY MEANS OF A SOLENOID

FIG. 221.—CURRENT INDUCED BY MAKING AND BREAKING THE CIRCUIT

245. Effect of Opening and Closing the Circuit in the Solenoid. If now the current-carrying coil is placed near the other (Fig. 221) and the circuit is opened and closed, a current will be set up in the other coil even though there is no motion of the coils.

In all of these cases the current set up in the coil connected

to the galvanometer is called an *induced current,* and the phenomenon is called *electromagnetic induction.* In the cases where current-carrying coils are used, they are called the *primary circuits,* and the other in which the current is induced is called the *secondary circuit.* In the first two cases, where a permanent magnet, solenoid, or electromagnet was moved, it is apparent that there has been a motion of the magnetic lines of the field about them. These have been disturbed or *cut* by the wires of the secondary coil. This cutting of the magnetic lines is not so apparent in the case of opening and closing the primary circuit, but if we stop to consider that the magnetic field about the primary coil appears only after the current is set up, and disappears when it ceases, it is easy to see that there is an interval in which the lines are moving outward on the closing of the circuit and inward toward the coils on the opening of the circuit. During this interval the lines are cut by the secondary coil, and it is then that a current is induced in this coil.

246. Direction of the Induced Current. In the above experiments we found that the direction of the induced current through the secondary coil was opposite on the closing from what it was on the opening of the primary circuit, and that there was a difference on the approach and on the separation of coils, or of the coil and the magnet. If the course of the secondary current is traced in each case, it will be found that it is such as always to present a pole toward that of the magnet or primary coil that is like it on the approach and unlike it on the separation. For example, if the north pole of the permanent magnet, solenoid, or electromagnet is the one toward the secondary coil, the current induced in the latter will be such as to present a north pole on approach and south pole on separation. Where the primary circuit is made and broken a like condition results.

247. Intensity of the Induced Effect. Close observation of the distance the galvanometer needle swings to the right or to the left in the above experiments shows that the faster the motion takes place, the greater is the induced current, as shown by the greater swing of the needle. Furthermore, if we strengthen the magnetic field, with the same rate of motion, a greater induced effect results. The field may be strengthened by sending more current through the primary coil. If the concentration of the magnetic lines is increased by the use of an iron core, or by an increased number of turns in the primary circuit, greater induction takes place. Each of these changed conditions results in a greater number of lines being cut by the secondary coil in a given time.

Inasmuch as the motion of the magnetic lines outward on the make and inward on the break of the primary circuit is almost instantaneous, we should expect and do get the greatest effect by the make and break method of induction.

248. To summarize:

1. Whenever there is a change in the magnetic field in the neighborhood of a closed coil of wire, whereby the magnetic lines are cut by the coil, a current is induced in the latter.

2. The direction of the induced current depends upon whether the magnetic field about the closed coil is becoming greater or less (approaching or receding). In all cases it is such that its resulting magnetic field opposes the change.

3. The strength of the induced current depends upon the number of magnetic lines cut in a given time by the closed coil.

249. Telephone. One of the most useful inventions to mankind has been the *telephone,* which has enabled us to converse at a distance with one another and thus save much time both in business and in the home. In this the principle of elec-

tromagnetic induction finds, together with the dynamo, a most wonderful application. By means of the telephone, instantaneous reproduction of the human voice and other sounds has been made possible.

We have learned in the study of the phonograph (Section 192) that sound waves set up by the human voice are capable of setting up vibrations in a disc, and, *vice versa,* that these sound waves may be again set up when the disc is made to vibrate by mechanical means. We have also learned that any change in the magnetic field about a closed coil will set up a current in that coil (Sections 243–245). Now soft iron is very permeable to magnetic lines, and therefore when it is placed in a field, as in

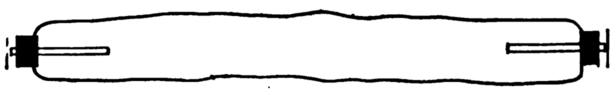


FIG. 222.—SIMPLE TELEPHONE CIRCUIT

the case of a magnet keeper, the lines, instead of spreading out through the air, concentrate in the iron (Fig. 180). Any movement of the iron changes these lines. If a coil is placed over a pole of the magnet (Fig. 222), and an iron disc is placed near the end of the magnet, the lines, as they change, when the iron disc moves back and forth, will be cut by the coil, in which a current will be induced. If the ends of the coil are connected with a coil on a similar magnet pole, the current flowing in this second coil will alternately strengthen and weaken this second magnet, as the induced current alternates in its direction. An iron disc placed close to this pole will thus be attracted in varying degrees, according to the changes produced by the vibration of the iron disc at the other end. The disc vibrations produced by the sound waves from a person speaking will thus be repro-

duced at the other end of the line.[1] These two receivers thus connected form a simple *telephone circuit.* Our modern telephone has been developed by the addition of batteries, transmitter, and transformer, mentioned later. For the present let it suffice to assume that the transformer intensifies the effect. The batteries give a current the strength of which is changed through induction.

250. Microphone Transmitter. Figure 223 represents a piece of apparatus called a *microphone.* It consists of a wooden

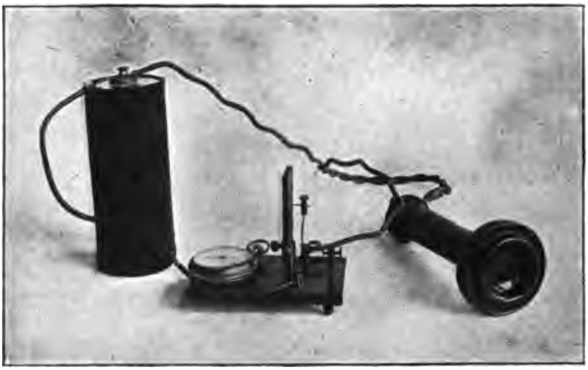


FIG. 223.—MICROPHONE

base to which are fastened a carbon plate and a flexible copper strip. Fastened to the upper end of this copper strip is a piece of copper wire which rests against the carbon. By means of a thumb screw the pressure between the carbon and the copper may be very delicately adjusted, so that the slightest vibration of the base board will produce a change in this pressure.

[1] It must clearly be borne in mind that the sound waves do *not* pass through the wire. It is the variation in the current strength that is the means by which the reproduction of sound is brought about.

Let us attach the secured ends to a cell with a telephone receiver in the circuit, and place a watch upon the horizontal board. The vibrations set up in the board by the ticking watch change the contact between the copper and carbon. Variations in the strength of the current flowing through them are produced and are perceptible in the receiver, so that the ticking of

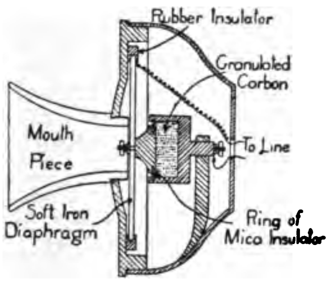


FIG. 224.—MICROPHONE TRANSMITTER

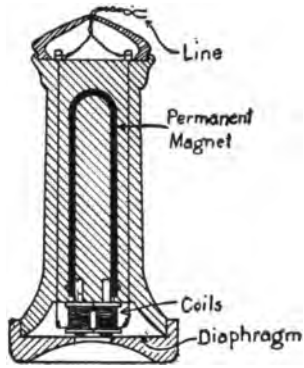


FIG. 225.—HORSESHOE RECEIVER

the watch is plainly heard. In the modern Blake transmitter (Fig. 224) the carbon has been replaced by a little cup of granulated carbon, and a soft iron diaphragm replaces the wooden base. Modern receivers are made of horseshoe magnets (Fig. 225) to get an increased effect.

QUESTIONS

1. Upon what fundamental action does an induced current depend?

2. Why does the amount of this induced effect depend upon the strength of the field?

3. When a closed coil is brought up to a north pole, in which way will the induced current flow?

4. Why does an electromagnet used as a primary produce a greater effect in the secondary than does a solenoid?

5. Why is a telephone receiver more sensitive when a horseshoe magnet is used than when a straight bar magnet is used?

6. Is the magnet in a telephone receiver a permanent one or an electromagnet?

7. Make a drawing showing the condition of the magnetic lines about the poles of a horseshoe telephone receiver (1) with the diaphragm off and (2) with the diaphragm in place.

8. Why must the diaphragm not touch the magnet in the telephone receiver?

251. Electromagnetic Induction as Applied to the Dynamo. Since a cutting of magnetic lines is needed to set up a current in a closed coil, a continuous cutting of these lines will produce a continuous current. In fact, if we rotate a coil between the poles of a magnet, we do get such a current, but it flows through the coil first one way and then the other, changing every half revolution. When the coil *a b c d* (Fig. 226*a*) is rotated in a clockwise fashion as indicated, a current will be induced that will flow in the direction *a b c d*, so as to get a north pole on the right and a south pole on the left. The attraction between the south pole of the magnet and the north pole of the coil, and between the north pole of the magnet and the south pole of the coil, opposes the motion of the coil. When the coil has passed through one half revolution (Fig. 226*b*), *c b* is on top and *a d* is below. During the next half revolution the induced current will flow in the direction *b a d c*. No matter which wire is on top, the current will flow down-

ward in the front wire *a b,* and upwards in the back wire *d c.* Let us cut the wire *a b* and fasten the cut ends to rings

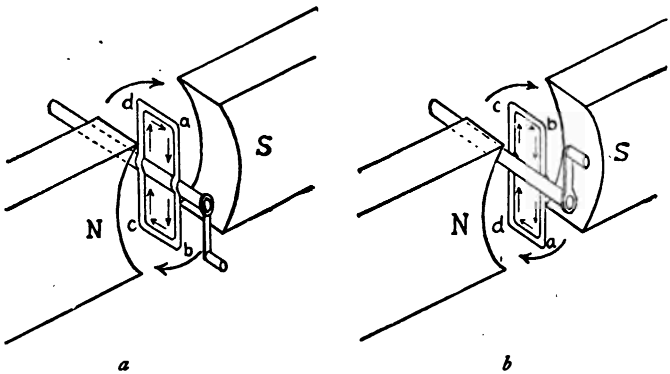


FIG. 226

(Fig. 227), and rest upon these rings strips of metal called *brushes,* which are connected to some outside circuit. When the coil is rotated we get a current flowing through this circuit first one way from x to y and then the other way from y to x, according as *a d* or *b c* are above. Such a current, which changes its direction as the coil rotates, is known as an *alternating current.* This sort of current has its uses, as we shall see later, but for many purposes a current that flows always the same way, as from a cell, is wanted. To get this from a dynamo as above described we must resort to a device known as a *commutator.* In this (Fig. 228) the ends of the wire from *a* and *b* are fastened to half rings placed one above the other. It can

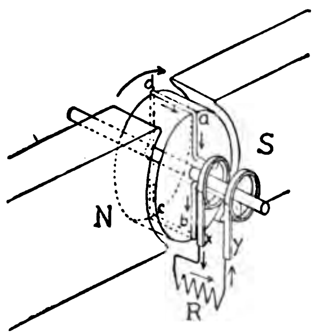


FIG. 227

now be seen that as the coil rotates the upper brush will always be touching the half ring which is connected to the side of the coil that moves downwards, and through which the current is flowing toward this upper brush. The half rings alternate in passing under this brush as the coil rotates. The change takes place when the coil is in the vertical position. As a result we get in the outside circuit *R* what is called a *direct* or unidirectional current. The rotating coil is called the *armature*. The magnet that furnishes the magnetic field is called the *field magnet.*

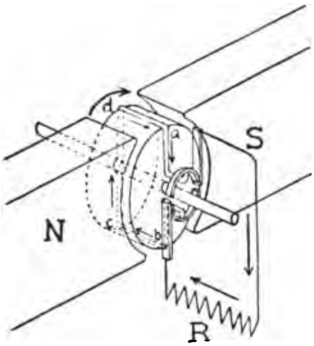


FIG. 228

By making the magnetic field stronger or by using a larger number of turns in the rotating coil, or by making the coil rotate faster, we can increase the effect and thereby get a greater current in the external circuit.

252. **Electric Motor.** With the development of the dynamo, making possible the use of electricity in large amounts, came the extended use of the magnetic effect produced by the electric current in the form of the electric motor. In this a current is sent first through the field magnet to produce field poles, and secondly through the armature in which poles are also produced. With the commutator segments and brushes so placed that the magnetic lines passing from pole to pole of the armature on the one hand, and those between the field magnet poles on the other hand, are not parallel, there is always an attraction between the unlike poles and rotation results. Almost any dynamo may be used as a motor. The direction of rotation with the same

direction of outside current will, however, be opposite. We find extended use of the direct-current motor in running sewing machines, washing machines, ice cream freezers, and fans. There is a form of alternating current motor called the *Induction* motor, which is used very commonly, where the alternating current is the source of supply. The explanation of this type of motor is, however, too complicated to be discussed here.

MEASUREMENT OF ELECTRICITY

253. We have thus far used such terms as quantity of electricity, electric current, pressure, without making any attempt to explain their meaning, on the assumption that for the purpose their meaning was understood.

254. **Electrical Pressure—Volt.** At the end of Static electricity the term difference in potential was explained as a difference in charged condition, as a result of which a current flowed from a higher charged object to a lower charged one when the two were connected by a conductor. This difference in potential lies behind the force that drives the electricity through the wire. This force is called *electromotive force* (E. M. F.) and is measured in terms of *volts,* after Volta.

255. **Electrical Resistance—Ohm.** Inasmuch as in all cases where action results, some opposition must be overcome by some force, we speak of this opposition to the flow of the electric current, which must be overcome by the electric pressure before a current flows, as the *electrical resistance.* It varies greatly in different substances. The unit by which it is measured is called the *ohm,* after Georg Simon Ohm. The ohm is the electrical resistance offered by a column of mercury 106.3 cm. long, of uniform cross section, and weighing 14.45 g. at a tem-

perature of 0° C. The resistance of a conductor in ohms depends upon four things: (1) its composition; (2) its length; (3) its size (area of cross section); (4) its temperature. The following table shows the relation between the resistances of wires of the same length and size and temperature, but of different composition:

Silver,	1	Zinc,	3.91
Copper,	1.06	Iron,	6.17
Aluminum,	1.81	Lead,	13.87

The resistance of a wire increases directly with increased length; decreases with increased size. Just as more persons can cross a wide bridge than can cross a narrow bridge at one time, so can more electricity flow through a large wire than can flow through a small one. A hot wire offers more resistance than does a cold one.

256. Electrical Current—Ampère. Whenever the electrical pressure of one volt overcomes a resistance of one ohm, a unit current of electricity flows through the conductor. This unit is the *ampere,* named after André Marie Ampère. Such a current deposits 0.001118 grams of silver per second upon the cathode in a silver electrolyte.

257. Relation between Ampère, Volt, and Ohm—Ohm's Law. When an electromotive force of *one volt* overcomes a resistance of *one ohm,* a current of *one ampere* results. This is known as Ohm's Law, which in its more extended meaning may be stated as *current in amperes* equals *volts pressure* divided by *ohms resistance.* More simply:

$$C = \frac{E}{R}$$

Thus with an E. M. F. of 10 volts and a resistance of 2 ohms a current of 5 amperes results. With any two of these three

quantities known, it is a simple matter to calculate the third; for

$$C = \frac{E}{R} \qquad E = CR \qquad R = \frac{E}{C}$$

In the above form R stands for the total resistance of both internal and external circuit, *i. e.*, that of the wire, lamps, or motor on the one hand, together with that of the source (battery or dynamo), on the other hand.

For all calculations on the succeeding pages, which deal only with the commercial electric current as supplied to houses, R stands for the resistance of the external circuit, which is all that need be considered. The commonest form in which this resistance occurs is in the wires that go to make up the various electrical apparatus. Simplest of these is the wire of the incandescent lamp. In this the resistance is very large and the heating effect so great that light results. In some cases a heating effect of less intensity is desired, as for cooking, ironing, and for heating purposes. In other cases the heating effect is of minor consequence, and is a hindrance rather than a help; for in these the magnetic or electrolytic effects are desired, as in bells, in electroplating, and in motors.

258. **Measurement of Electric Power—Watt.** In the measurement of the amount of electricity used, in order to determine the charge to be made the users, three things are considered: (1) the current, (2) the E. M. F. (voltage), and (3) the time interval during which the flow has occurred. Inasmuch as the resistance determines the current, this, too, may be said to enter into the calculation. The number of amperes multiplied by the volts pressure gives the unit of electric *power*, called the *Watt*. One ampere at a pressure of one volt yields

one volt-ampere, or one watt. If one ampere at one volt pressure flows for one hour, a *watt hour* results. Since a watt hour is a very small quantity, the *kilowatt hour,* which equals 1,000 watt hours, is generally used. It is this for which we pay and in the terms of which bills are rendered. A current of 10 amperes at 100 volts pressure gives 1,000 watts or 1 kilowatt. If this current flows for one hour, a kilowatt hour of electric energy has been expended.

A current of 5 amperes at 220 volts pressure corresponds to exactly the same number of watts as do 10 amperes at 110 volts pressure; for the products in the two cases (5×220 and 10×110) are equal. A current of 10 amperes at 110 volts pressure flowing for one hour represents the same number of watt hours as does a current of 5 amperes at 110 volts flowing for two hours; for $10 \times 110 \times 1$ hour equals $5 \times 110 \times 2$ hours.

259. Watt Consumption of Different Electrical Apparatus. The electricity supplied to houses is at a pressure of 110 or of 220 volts. The former is the commoner, and it is on such circuits that lamps, heating appliances, and small motors are run. Incandescent lamps in use are those with carbon or tungsten filaments. They are nowadays rated according to their watt consumption. Formerly they were graded with reference to their candle power, 4, 8, 12, 16, 32, etc., candle power, according to the brightness of the light they give. Increasing candle power of course required greater watt consumption. For equal candle power the consumption of the tungsten lamp is a little less than one-half that of the carbon type. A sixteen candle power carbon light, requiring 55 watts, is now being replaced by the 25-watt tungsten light. The tungsten filament is, however, much more easily broken than the carbon filament, and such a lamp requires very careful handling. The current that

flows through each of these can easily be calculated by substituting the voltage 110 and the watts 55 and 25 respectively in the expression

$$\text{watts} = \text{volts} \times \text{amperes}.$$

$$(1) \quad 55 = 110 \times \text{amperes}.$$

$$\tfrac{55}{110} = .5 \text{ amperes, for the carbon light.}$$

$$(2) \quad 25 = 110 \times \text{amperes}.$$

$$\tfrac{25}{110} = .227 \text{ amperes for the tungsten light.}$$

The following table gives the watt consumption of the electrical appliances mentioned:

Electric Toaster, 600.
Electric Iron, 300–700.
Electric Percolator, 450.
Electric Instantaneous Water Heater, 350–600.
Arc Light, 1,000–3,500.
Home Kinetoscope Arc Lamp, 550.
Large Moving Picture Arc Lamp, 3,500–5,000.
Large Projection Lantern, 1,000–2,000.
Electric Warming Pad, 40–100.
Electric Heater, 100–1,500.
Fan Motor, 18–80.
Sewing Machine Motor, 25–50.

260. Voltages of Different Electrical Sources. Ordinary cells such as those used in houses for electric bell ringing furnish between 1.5 and 1.8 volts each. By joining several cells together higher voltages may be secured. (See Section 263.)

The E. M. F. of the commercial electric circuit is either 110 or 220 volts, usually the first. On the trolley car circuit, 550 volts are employed. The new Edison nickel storage cell gives 1.2 volts. The voltage of a charged lead storage cell is 2.

261. Series and Multiple Connection of Conductors. Since resistance increases with the length, joining wires end to end produces a combined resistance equal to the sum of the separate ones (Fig. 229). Such a method is called joining in

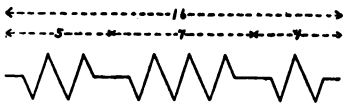


FIG. 229.—WIRES JOINED IN SERIES

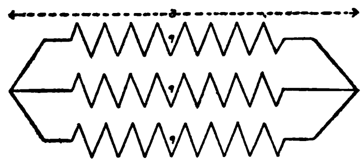


FIG. 230.—WIRES JOINED IN MULTIPLE OR PARALLEL

series. Now if both ends of three wires are joined together (Fig. 230), each wire will carry its separate current, and we get as a result the same effect as would be secured by increasing the size of the wire. This method is called joining in *multiple* or *parallel,* and results in a combined resistance less than that of any one of the separate conductors.

The greater the resistance of a wire the less current it carries, *i. e.*, the less conducting power it has, under the same pressure. The conductance decreases as the resistance increases. The unit of conductance is called the *mho*. This is equal to the reciprocal of the resistance in ohms, or $\frac{1}{R}$. If then two conductors connected in parallel have conductances $\frac{1}{R}$ and $\frac{1}{R_1}$, the combined conductances of the two will be the sum of their separate conductances, since each offers a separate path for the current. If $\frac{1}{R_x}$ equals their combined conductance, then $\frac{1}{R_x} = \frac{1}{R} + \frac{1}{R_1}$. By substituting the values of R and R_1 in this equation, the value of R_x can be easily calculated. For example, if two wires

of 2 and 3 ohms resistance are connected in parallel, the equation becomes $\frac{1}{R_x} = \frac{1}{2} + \frac{1}{3}$.

Solving: $6 = 3R_x + 2R_x \quad 6 = 5R_x \quad R_x = 1\frac{1}{5}$ ohms.

If the separate resistances are equal, then the solution of the problem becomes quite simple; as the combined resistance becomes equal to that of a single one divided by the number joined in parallel. (See Fig. 230.)

We meet with just such a situation in the grouping of incandescent lamps in houses (Fig. 231). The wires to which the lamps are attached are at 110 volts E. M. F. When an additional

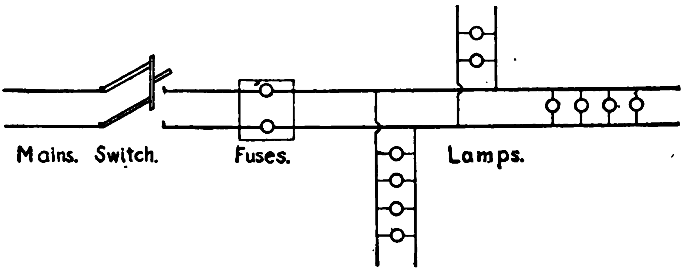


FIG. 231.—LAMPS IN HOUSE GROUPED IN PARALLEL

lamp is lighted, the combined resistance is diminished and the total current through the wires increases proportionally. One way of arranging the lighting wires in a house is shown in Figure 232. Just inside where the main wires from the street enter a house, fuses are inserted so that if the wires become crossed anywhere in the house, thereby producing a short circuit, the fuse will melt and shut off the supply. Otherwise the very large current and resultant heating effect produced by the large current flowing through a very small resistance would cause fire.

Where small low voltage lamps are used on the house circuit for decoration, such as on Christmas trees, they are joined in

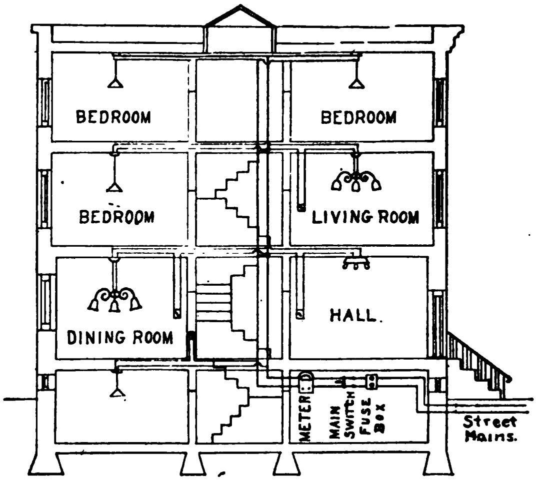


FIG. 232.—HOUSE WIRING DIAGRAM

series in sufficient number to make the combined resistance of them equal to that of a single 110-volt lamp, *i. e.*, 55 two volt lamps, 28 four volt lamps, etc. If they were not so connected, the current would be too strong and they would burn out.

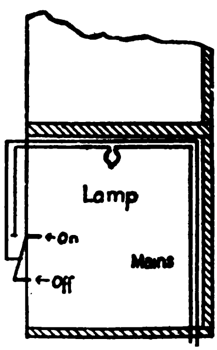


FIG. 233.—WALL SWITCH

262. Control of Lights. Sometimes it is an advantage to turn on the light from a switch on the wall instead of at the light itself. In that case one of the wires from the mains passes to the switch first and an extra wire passes from the switch to the lamp (Fig. 233). The key at the lamp is always left on.

In case one wishes to turn a light on or

off either up or down stairs, three-way switches are used. The connections for such switches are shown in Figure 234. The light may be turned on by either the upstairs or downstairs switch, as the circuit is thereby completed.

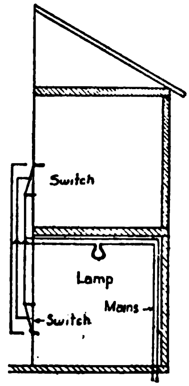


FIG. 234.—UPSTAIRS AND DOWNSTAIRS CONTROL OF LIGHT

263. Grouping of Cells. Although the zinc carbon cells furnish a higher voltage (1.8) than most others, being formed of metals far apart in the electrochemical series (Section 215), sometimes a greater pressure (electromotive force) is desired. In such a case two or more cells are used together, forming a battery. They are then connected in *series,* the zinc of the first to the carbon of the second, the zinc of this to the carbon of the next, and so on (Fig. 235*a*). The carbon of the first and the zinc of the last are thus free, and to these are fastened the wires that pass to the bell or other circuit on which such a grouping is used. The combined electromotive force is found by adding together the electromotive forces of the separate cells.

Cells may also be joined in *parallel,* just as electric lights. In this case the zincs of all the cells are joined together, and the carbons are also joined together (Fig. 235*b*). To the combined carbons and to the combined zincs, wires are fastened. These are connected to the apparatus to be used. The E. M. F. of such a battery is the same as of a single cell, the effect of such a grouping being the same as increasing the size of the plates. As a result, owing to the greater number of paths for the current through cells, the internal resistance of the battery is decreased.

Where small low vol
for decoration, such as

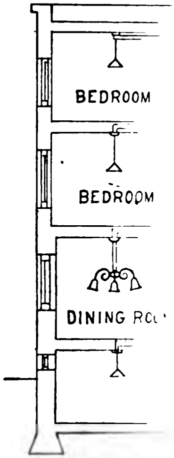


FIG. 232

series in sufficient num
them equal to that of
lamps, 28 four volt lam

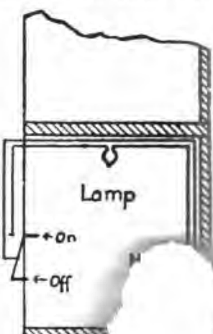


FIG. 2
S

amperes carried by each piece, using the maximum figures given.

2. What is the resistance in ohms of each of the pieces of apparatus in this table?

3. With electricity at 13 cents a kilowatt hour, how much does it cost to use a 50-watt 20 candle power carbon incandescent lamp for an evening of four hours?

4. At the same cost of electrical power, how much does a 40-watt 32 candle power Mazda tungsten lamp cost for an evening of four hours?

5. How much per candle power of light obtained does a 50-watt 20 candle power carbon lamp cost for an hour's use?

6. Calculate the cost per candle power hour when a 40-watt 30 candle power tungsten lamp is used.

7. Which is more economical, five 40-watt lamps giving 32 candle power apiece, or two 100-watt lamps giving 80 candle power apiece?

8. How many amperes pass through a 50-watt lamp on a 110-volt circuit?

9. Calculate the resistance of a 40-watt Mazda lamp that is used on a 110-volt circuit.

10. Calculate the resistance of a 100-watt 80 candle power Mazda lamp used on a 110-volt circuit.

11. How many amperes current will pass through the mains if five 40-watt Mazda lamps are placed on the circuit in parallel?

12. An instantaneous water heater consumes 350 watts. With e[illegible] at 10 cents a kilowatt hour, how much would it [illegible] an of water if it takes 5 minutes to do so?

[illegible] heating pad is rated at 60 watts. How much [illegible] e such a pad for 12 hours?

264. Flash Lamps. In the pocket flash lights so frequently used, the lamps require a very low E. M. F., varying between 2 and 6 volts, since the source is from cells. The required voltage is secured by forming a battery of two or more dry cells

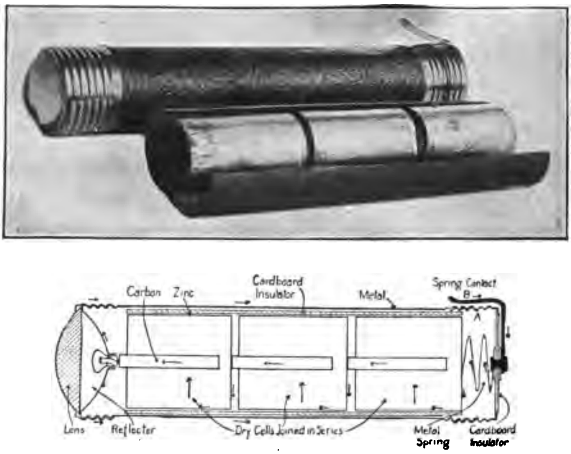


FIG. 236.—FLASH LAMP

connected in series, the carbon of the first one pressing against the disc of the lamp and the zinc of the last one being connected through the metal holder to the screw ring (Fig. 236).

265. Measuring Instruments. These are of three kinds, *ammeters* for *current*, *voltmeters* for *E. M. F.*, and *wattmeters* for *power*. In all of them the magnetic effect of the current is the underlying principle involved; the magnitude of this depending upon the strength of the current. Such instruments usually consist of a coil of wire in the field of a permanent magnet (see Fig. 219). Indication of the magnetic effect is shown by a pointer which moves across a graduated dial. A

coiled spring becomes tighter as the pointer moves. This offers an opposition, which, on the one hand, keeps the pointer from moving too far, and, on the other hand, when the current ceases, acts to force the pointer back to the zero mark.

An ammeter is a shunted galvanometer (Fig. 237), in which the conductance of the shunt is so great, as compared with that

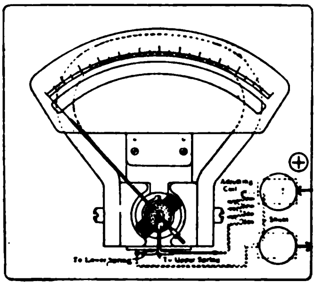


FIG. 237.—AMMETER

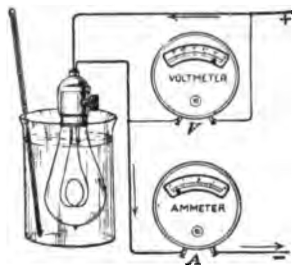


FIG. 238.—AMMETER AND VOLTMETER IN USE

of the moving coil, that a very small proportion of the current that flows through the instrument passes through the coil. Ammeters are placed on the line so that all the current passes through the instrument (Fig. 238).

A voltmeter can be made of the same galvanometer as was the ammeter, by placing a coil of large resistance in series with the movable coil (Fig. 239). The resistance of the voltmeter is so large that very little current passes through it. Voltmeters are placed across the line (Fig. 238), and register the pressure (E. M. F.) between the two wires of the line.

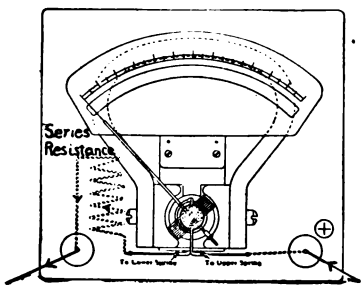
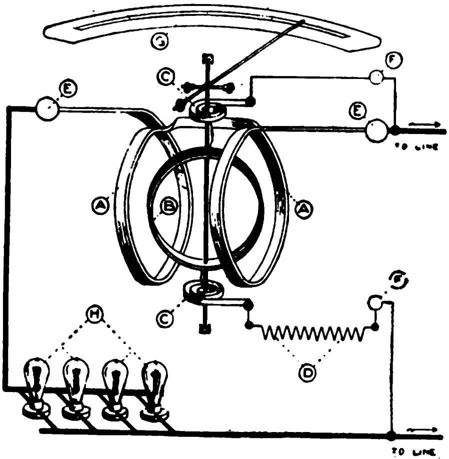
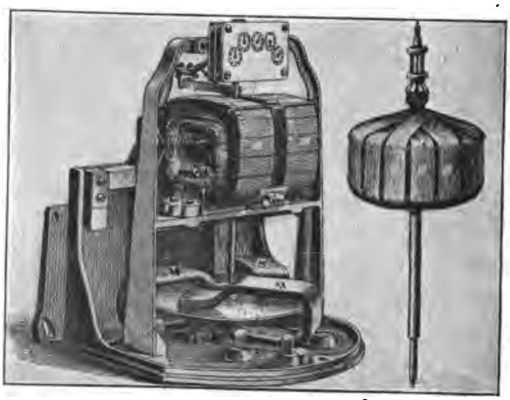


FIG. 239.—VOLTMETER



a



b

FIG. 240.—(*a*) INDICATING WATTMETER
(*b*) RECORDING WATT HOUR METER

A wattmeter may be looked upon as a combined voltmeter and ammeter. In this (Fig. 240*a*) the magnetic field is formed, not by a permanent magnet, as in the case of a voltmeter or ammeter, but by the current that flows through two coils *A A* joined in series to the terminals *E E*. All the current which passes through the lamps *H* (which represent the load) passes through these field coils. The strength of the field thus produced depends upon the magnitude of the current used.

The movable coil *B* is connected,

as is a voltmeter, across the line to the terminals *F F* through the springs *C C*. In series with this movable coil is a resistance *D* which prevents too strong a current flowing through the coil. The magnitude of the current through the movable coil depends upon the E. M. F. between the line wires. The amount the movable coil turns out of its position of rest depends upon the combined effect of the magnetic fields of the field coils *A A* and of the movable coil *B*, increasing with an increased current through either. A pointer moving across the graduated dial *G* indicates the product of what determines the strength of these two fields (amperes × volts = watts). There will always be a current flowing through the movable coil *B*, just as long as there is any supply in the main line. It will show no effect on the pointer, however, because there will be no magnetic field around the coils *A A* until a current flows through some apparatus, as lamps, a motor, or heating appliance.

House wattmeters are of the recording type, in which the springs are removed from the movable coil. A motor effect is produced and by a series of cogs the watt hour consumption is registered on a dial (Fig. 240*b*). For greater convenience the measurement is made in kilowatt hours. To prevent too rapid motion of the rotating coil, there are permanent magnets *m, m, m,* which, acting upon an iron disc, retard the movement.

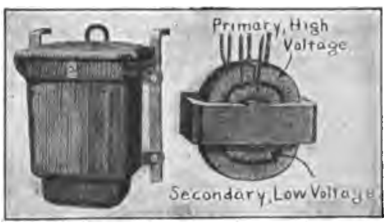


FIG. 241.—TRANSFORMER

266. Transformer. If we examine the poles on which are strung the wires that supply the electric light to houses, we see on some of them an iron box like Figure 241.

To this box are attached wires, some of which are connected to houses near by, while others come along the poles from some distant source, the power house. These boxes are *transformers,* used to reduce the voltage of the current. Through these wires an alternating current is supplied whenever the locality is a long distance from the power house. To customers living *near* the power house a direct current is usually supplied and transformers are unnecessary.

A large current of electricity in the form of a direct current supply, when sent a long distance, requires a very large wire. Otherwise with a small wire there is a large loss of electrical energy caused by the heating effect in the wire. In proportion to the energy delivered at the end of the line, this loss is so large as to make the cost to the producer excessive. The loss in the wire is due to the large resistance that must be overcome in such a long conductor.

Now the watt consumption is found by multiplying current in amperes by electromotive force in volts. A large current at low voltage furnishes the same amount of electrical energy as does a small current at high voltage. For example, 10 amperes at 2,200 volts give 22,000 watts; 100 amperes at 220 volts also give 22,000 watts. If then a supply at 2,200 volts and 10 amperes can at the end of the line be turned to a supply of 100 amperes at 220 volts, we can use much smaller wires to carry the 10 amperes than would be necessary to carry the 100 amperes. This change cannot be accomplished when the direct current is used. The alternating current, because of its rapid surging first one way and then the other, back and forth through the wire, furnishes a constantly changing magnetic field. This affords a means of inducing a current in a coil placed in the neighborhood of another coil through which the alternating current passes.

Referring to electromagnetic induction (Section 248), we find that consideration was given only to changes in the *magnetic field* of the *primary coil.* The secondary coil in all cases was kept the same, both as to size and number of turns. Let us now see what will be the effect of changing the number of turns in this secondary coil. Since the induced electrical pressure in the secondary coil depends upon the number of magnetic lines cut by it in a second, an increase in its number of turns will increase the rate of cutting and thereby increase the induced effect. Now it can be shown that if the two coils, primary and secondary, have the same number of turns, the electromotive force induced in the secondary coil will be equal to that between the terminals of the primary coil. If there is a difference in the number of turns, there will be a corresponding difference in the two electromotive forces, the greater E. M. F. being in the one having the greater number of turns. An arrangement of two coils on the same iron core, made up of rings of sheet iron, is called a *transformer* (Fig. 242). We have "step up" or "step down" transformers, according as the secondary coils have a larger number or a smaller number of turns than do the primary coils. In the case of the electric light supply the transformer is a "step down" one, the primary being supplied from the power house at 1,100 volts and the secondary delivering 110 volts (Fig. 243). This low voltage is necessary in houses, as the higher voltage is dangerous to human life.

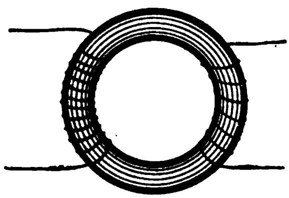


FIG. 242.—SIMPLE TRANSFORMER

In a house itself use is sometimes made of a "step down" transformer as a substitute for a battery for ringing electric

bells, for running electric toys, and for the small home moving picture machines. Such transformers can be used only in houses where there is an alternating current supply.

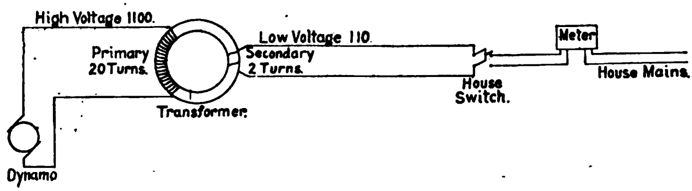


FIG. 243.—TRANSFORMER ON HOUSE CIRCUIT SUPPLY

QUESTIONS

1. What will be the effect of joining two 40-watt tungsten lamps in series across a 110-volt main in a house?

2. Calculate the current that passes through two such 40-watt lamps joined in series.

3. What change takes place in the current each time an added lamp is turned on in a house?

4. How many 50-watt lamps can be used in a house fused for 10 amperes?

5. Would it be possible to run a 500-watt electric iron and ten 50-watt incandescent lamps on a circuit fused for 10 amperes?

6. If eight 14-volt Christmas tree lamps are connected in series and lighted, what will happen if one of them breaks?

7. If ten 40-watt Mazda lamps are lighted on a house circuit, what will be the result if one of them breaks?

8. Why is it proper to call the source of electricity as used on a pocket flash lamp a battery?

9. How are dry cells connected for use in ringing bells? Explain why they must be joined this way.

10. A bell requires a little over 2 volts to make it ring. What is the fewest number of dry cells that will ring it?

11. If the outside voltage on the lighting circuit should become higher than the standard 110 volts, what effect would be produced on the lamp if it is turned on? What will be the effect on the wattmeter? Explain.

12. Compare the cost of using one 40-watt Mazda light for an evening of four hours, with that of a Welsbach upright gas light (see Section 98 and questions). Consider that electricity costs 13 cents a kilowatt hour, and gas costs one dollar a thousand cubic feet.

13. A 40-watt Mazda light gives about 32 candle power. Compare this with the Welsbach light as to cost per candle power. Which is the more economical?

14. Which is cheaper for a hall light: a Welsbach Junior gas light or a 15-watt Mazda light?

Review Questions

1. Describe an electromagnet, naming all the parts, and the use of each.

2. What is the best method of making a strong permanent magnet?

3. State two reasons why soft iron and not steel is used for the core of an electromagnet.

4. What is meant by permeability, and to what does it apply most?

5. What is meant by retentivity, and to what does it apply most?

6. What is the difference between E. M. F. and difference in potential?

7. Why is it that we get a current when two unlike metal strips placed in a liquid are connected, and do not, when two metal strips of the same material are used?

8. Draw a diagram showing how the magnetic lines are arranged when two bar magnets are placed parallel to each other (1) with unlike poles opposite and (2) with like poles opposite.

9. What is meant by breaking an electric circuit?

10. Why must great care be exercised in bringing strong magnets near small compass needles?

11. No matter what metals are used in a cell, which one is + and which — in the external circuit?

12. How are silver cups gold-plated on the inside only?

13. If the electric light in a room in which you are reading should suddenly give out, what steps would you follow to locate the cause?

14. A 6-lb. electric iron consumes 575 watts. A 6-lb. gas iron consumes 20 cu. ft. of gas per hour. Compare the cost of a day's ironing of eight hours for each iron.

CHAPTER VI

MECHANICS

Energy. Force. Work.
- Weight.
- Friction.
- Inertia.

Mechanics of Solids.
- Pressure Intensity.
- Balanced and Unbalanced Forces.

Machines.
- Lever and Inclined Plane.
- Mechanical Advantage.

Center of Gravity.
- Stability.
- Pendulum.

Mechanics of Liquids.
- Pressure in Liquids.
- Buoyant Effect of Liquids.

Mechanics of Gases.
- Atmosphere.
  - Barometers.

Pumps.
- Air Pumps.
- Water Pumps.
  - Lifting Pump.
  - Force Pump.
- Siphon.

Mechanics of Molecules.
- Adhesion and Cohesion.
- Capillarity.

267. Energy. We have learned (see Section 3) that the cause of all changes that go on about us is *energy*. This energy may be due to the position of an object with reference to its distance above the surface of the earth, or it may be due to the condition of the object. A stone or other object above the earth is capable of producing effects upon other objects when it is released and allowed to drop. A coiled spring of a clock, as it uncoils, makes the wheels revolve. The energy in coal, when it is set free, while the coal burns, cooks our food and warms the house. Electricity that flows through wires rings the doorbell or furnishes us with light in the incandescent lamp. In all these cases we have what is called *stored up* or *potential* energy.

On the other hand, a stone flying through the air will break a window it may strike; a hammer, when used for pounding, will drive a nail into a board; a tennis racket, when swung against the on-coming ball, sends it off in another direction. In these cases some moving object has brought about the change sought. Such energy of moving objects is called *kinetic energy*.

268. Force. Thus far we have used the terms force and pressure in the sense of agents through which various forms of energy have brought about the changes described. In many cases only the qualitative side of this force has been considered. The quantitative side of it will be discussed more in the pages that follow. As it happens, forces are measured in the same unit as are weights. In fact, weights *are* forces. When we weigh things we place them upon something, which is thereby pulled or pressed down. The common means of weighing is the spring scales (Fig. 244). In it the coil of wire, or spring, is stretched by the weight of the object pulling down upon it. The spring possesses a characteristic known as *elasticity*, because

of which, when the weight is removed, the coil returns to its former condition. The distance the coil stretches depends upon the strength of the force, and increases at the same rate. If we hang upon the hook a weight that represents the standard pound, the pointer will move downwards a certain distance. If we mark its position on the scale and replace the weight by one twice as heavy, the pointer will move twice as far; and with half the weight it will move half as far. By dividing the spaces equally, we can form a scale by which the weight of anything up to the limit of that scale can be determined.

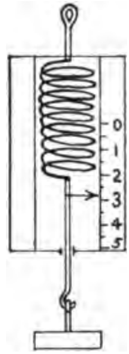


FIG. 244

Energy and *force* must not be confused. Behind all forces is *energy*. Energy is a property or characteristic, while force is a representation or agent of energy, through which the existence of energy is made apparent.

269. Weight—Gravity. What is weight? This can best be answered by stating that there is some force that attracts objects to the earth. If they are raised or carried above the surface they will return when there is nothing to keep them from dropping. There is an attraction that exists between the earth and objects on it, as well as between the earth and the moon, and between the earth and the sun. To this attraction of the earth for objects on it, is given the name *gravity*. The downward pressure of any object caused by gravity is called its *weight*. Different objects weigh differently because they are composed of different amounts of substance upon which gravity can act.

270. Characteristics and Effects of Forces. We can have forces other than those due to gravity, as we have already

learned. While weight acts downwards always, these other forces may act in any direction. All forces must act upon something, in some definite direction, and with a certain intensity. To these characteristics of a force are given the terms *point of application, direction* and *magnitude,* respectively.

Sometimes the forces act alone, sometimes together, upon the same object. In the latter instance the effect produced will depend upon the direction in which they act. If they act in the same direction, the magnitude of the combined effect will be equal to their sum; as in the case of three or four persons pulling together upon a rope attached to a tree that is being pulled down. If they act in the opposite direction, the effect produced will depend upon which is the greater; and motion, if it results, will take place in the direction in which the greater force acts; as when we lift a box, we must pull up with a slightly greater force than the weight of the box. Finally, if the forces act neither opposite nor in the same direction, the effect will be in the direction of neither, but will be between them, and its magnitude will be greatest when they are most nearly parallel and least when they are most nearly opposite. In all these cases a single force may be substituted to take the place of the two original forces. To this single force is given the name *resultant.* In the case of an overcoat that hangs on a form from a clothesline (Fig. 245), the two parts of the line on either side are pulling towards the hook at each end, producing as a result an upward pull to hold up the coat. The two forces acting towards the hook are called *components.* They can be replaced by a single vertical resultant force which holds up the coat.

Just as two or more forces may be replaced by a single resultant force, so may any single force be broken up into any number of pairs of components. The coat may be supported by

the same two parts of the clothesline, though they may pull in directions anywhere between nearly parallel and nearly opposite. The intensity of the two pulls will be least in the former, and greatest in the latter case. The reason for this

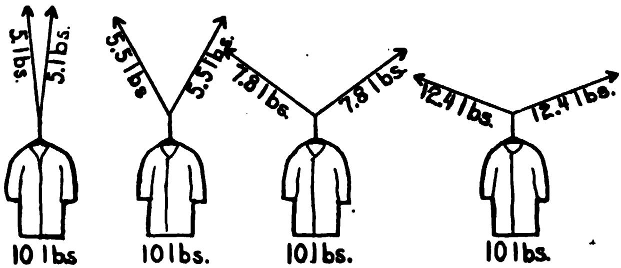


FIG. 245

is that when pulling in opposition they are not only supporting the coat, but are tending to pull against each other as well (Fig. 245).

271. Work. In all instances in which energy, either kinetic or potential, has been the means of bringing about a change, through its agent, force, *work* has been done. A change which involves motion of some sort must take place in order that work may be done. This change involves an expenditure of energy in overcoming some opposition known as *resistance*. The opposition may be due to various causes, such as *weight, friction, inertia*.

272. Friction. Whenever we light a match by rubbing its head across some rough surface, the head is heated sufficiently to set the phosphorus tip of

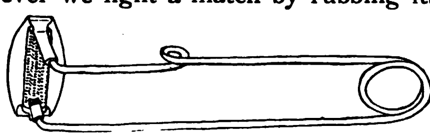


FIG. 246.—METALLIC GAS LIGHTER

the match on fire. In the metallic gas lighters used so much nowadays (Fig. 246), an alloy of iron and cerium is rubbed over a steel file, forming sparks, which light the gas. In the tinder, flint, and steel used by our ancestors, this principle of *friction* between two objects, rubbed or struck upon each other, was utilized. Friction is the resistance that objects offer to being rubbed one over the other. The act of overcoming it produces heat.

All surfaces are more or less rough (Fig. 247), and as one slides over the other, the projections on one alternately rise and fall over those of the other. The smoother the surface the less rise and fall there will be, and the less will be the friction. It is for this reason that we slip on ice and not on the ground. It is to reduce friction that floors are waxed for dancing; that drawer runners are waxed and wheel bearings are oiled.

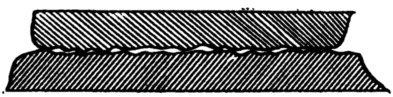


FIG. 247.—SLIDING FRICTION

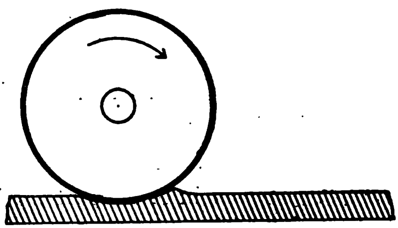


FIG. 248.—ROLLING FRICTION

273. Sliding and Rolling Friction. We are all familiar with the fact that a carriage wheel rolls over the ground much more easily than a sled runner slides over it. This is because the friction between a rolling object and the ground is much less than that between a sliding object and the ground. The wheel, as it rolls forward, compresses the part directly under it, thereby making a little ridge ahead of it (Fig. 248). The act of piling up this ridge is an overcoming of a resistance that the surface offers when

it is compressed. The larger the circumference of the wheel the less it tends to make a depression, and therefore the less is the resistance due to compression. Furniture fitted with castors of large diameter can be rolled about much more easily than when fitted with small ones, because of this lessened tendency to make depressions in the floor.

Questions

1. Can there be force without energy? Explain.

2. Name some instance that proves that sound is a form of energy. Do the same for heat; light; electricity.

3. A person holds a watch at arm's length for five minutes. Has he done any work? Explain.

4. What is the object of putting sand upon icy sidewalks?

5. Why can a person slide easily on ice but not on boards?

6. Why do cars slip on the rails when there are leaves on them?

7. Why must sewing machines be oiled frequently?

8. Why does an old-fashioned iron nail hold two pieces of board together better than do wire nails?

274. Inertia. Whenever we move anything from one place to another, we feel a certain opposition to the change. This opposition is greatest when the object is starting. After that it is less, and is due only to friction, so long as the motion is a steady one. We also experience a certain opposition if we try to stop a moving object, or make it move in another direction. This characteristic of objects, because of which an outside force must be exerted upon them to start them, stop them, or change their direction of motion, is called *inertia*. The

heavier the object is, the greater is the force that must be applied to bring about the desired effect.

It is because of *inertia of rest* that a person's head is jerked backwards when a carriage in which he is seated starts suddenly. The same is true when a person standing in the aisle of a street car facing the front of the car is thrown backwards as the car starts. In this last case the feet go forward while the upper part of the body, upon which no force acts, stays behind.

Just as force is needed to overcome the inertia of a body at rest, if we wish to set it in motion, so it is needed to stop or to slow down a moving object. In the process of shoveling coal into a furnace, the inertia of the moving coal causes it to leave the shovel when the shovel is stopped suddenly by the hands. For the same reason snow or mud leaves our shoes when we stamp them upon the ground.

Sometimes the effect sought is not to increase or decrease the motion of an object, but to change the direction. Here also force is necessary. Every one knows how difficult it is to turn around a corner quickly when running. A carriage or automobile going rapidly around a corner tends to skid or tip over outward, and persons in it brace themselves against the outer sides of the seat.

275. Effect of a Force Applied to Overcome Inertia. The effect produced by any force in setting an object in motion depends upon the point on the object at which the force acts, upon the direction in which it acts, and upon how quickly it acts. When a person's head is jerked backwards on the sudden starting of a carriage, the force acts upon the *body*, not upon the *head*. The body moves, but the head does not.

If the force acts perpendicularly to the surface, its effect is directly upon the object, which moves in the direction in

which the force acts. If, however, the force acts at an angle with the surface, the amount the object will move in the direction of the acting force will depend upon the amount of the friction. The force here divides into two component parts, one acting perpendicularly to the surface, the other acting parallel to it. The rougher the surface is the greater becomes the effect of this force parallel to it, and the more the object tends to move in the direction in which the force is acting. As an example, if a hammer strikes a glancing blow upon a nail, it will not drive the latter so far into the board as when it strikes the nail squarely. Furthermore, the nail is generally bent, because of the horizontal component of the striking force. The rougher the head of the nail is, the more the nail will be bent.

A piece of paper may be pulled from under a pile of coins without disturbing the coins, if the action is sudden enough. The force acting upon the under surface of the lowest coin is the friction between the metal and the paper, and is practically parallel to the two surfaces. This friction is not sufficient to overcome the inertia of rest of the pile of coins. For the same reason if a tray loaded with a pile of dishes is suddenly pulled sidewise when carried out of a room, the pile is likely to topple over, because the friction between the plates is so small.

In stopping objects that are already in motion, the force produces the greater effect the more directly it acts in opposition to the motion. In walking on ice or on a waxed floor, persons must exercise care by planting the foot squarely if they would avoid slipping. Dancers avoid the retarding action of the floor by *purposely* sliding about the floor.

The coal mentioned in Section 274 leaves the shovel for the reason that the friction between the iron and the coal is not sufficient to overcome the inertia of motion of the coal. When

the feet are stamped upon the floor or ground, the adhesion between the shoe and the mud or snow is not sufficient to overcome the inertia of motion, and the mud or snow continues to move.

The effect of that part of the applied force which acts perpendicularly to the surface of an object will depend upon how hard and rigid the surface is. A hard substance will respond to the blow and show a greater effect than will a soft, pliable one. Rubber tires on baby carriages are used for the purpose of lessening the jar. Pneumatic tires on automobiles are filled with air which yields readily to the sudden changes in the uneven road. Springs are put on carriages for the same reason. Here the inertia of the heavy body of the carriage is so great that the change in position takes place mainly in the tires and springs.

Sometimes when water faucets are suddenly shut off, a bumping noise is heard. This is due to the inertia of the moving water, which is stopped by the faucet. To prevent this bumping effect, air chambers are placed at the end of the pipe (Fig. 249) to act as a cushion. The force of the moving water is thus taken up slowly.

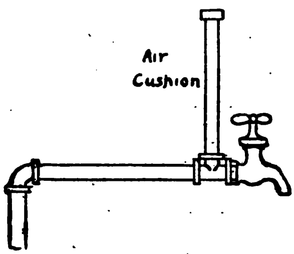


FIG. 249

Pneumatic door checks are used so that the door will shut more slowly, and not slam. The air cushion makes the force of stopping the door act less suddenly, so that a less intense effect is produced.

In the case of making an object change its direction of motion, the force that brings about the desired change in direc-

tion acts towards the center of the curve along which the change is to take place. The force, called *centripetal* (center pulling), is applied to pull the moving object out of a straight line of motion. The tendency of an object thus pulled to continue moving in a straight line is called *centrifugal tendency.* It is quite apparent in the case of water flying from the rim of a fast rotating grindstone. The direction in which the flying drops move is tangent to the curve of the rim of the stone. The magnitude of the centripetal force increases with an increased size of the object, increases with increased speed of the moving object, and increases as the direction of the path of the moving object becomes more curved.

An egg beater may be nearly freed from the adhering particles by rapid rotation of the hoops. Clothes are often dried in centrifugal dryers, consisting of large revolving barrels with many perforations in the sides. The water passes out through the holes, as the adhesive force between the water and the clothes is not sufficient to overcome the tendency of the moving water to go in a straight line.

276. Shade Roller and Cream Separator. In shade rollers the centrifugal tendency of the two loose-fitting catches (Fig. 250), as the shade is allowed to roll up rapidly, keeps the one on top from dropping into the slot. The slot does not rotate, since it is a part of the roller that fits into the bracket which supports the shade. If, however, the shade is allowed to roll up slowly, the catch drops into the slot and thus prevents further rolling.

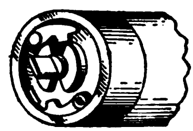


FIG. 250

We learned that a greater force is needed to pull heavy substances than to pull light ones from a straight line of motion.

From this it is easy to see that if a mixture of two liquids of different density, such as skim milk and cream, which together make up ordinary milk, are whirled together in a cylinder or tube, the cream will remain near the center and the skim milk will go to the outer part. This principle is utilized in the cream separator, by which the cream may be quickly separated, immediately after the milk is obtained (Fig. 251).

FIG. 251.—CREAM SEPARATOR

QUESTIONS

1. Why does beating a carpet remove the dust from it?

2. Why do rubber heels make walking easier?

3. Explain why a pail full of water may be swung over the head without any of the water falling out.

4. Why does a person lean toward the front of the car when it starts?

5. Of what advantage is the arch of the foot?

6. Why does food leave a spoon when the latter is struck sharply upon the edge of a stewpan?

277. Measurement of Work Done. It requires twice as much effort to raise forty pounds as it does to raise twenty pounds the same distance. Furthermore, to raise twenty pounds twice as high also requires twice as much effort. We thus see

that the work done, which is the result of the effort, depends upon how much force is applied and through how great a distance it acts. *Work done is equal to the force acting times the distance through which it acts.* The unit of work is generally expressed in *foot-pounds, gram-centimeters,* or *kilogram-meters.* Thus to raise one pound one foot higher involves one foot-pound of work. Two pounds lifted one foot involves 2 foot-pounds. Two pounds lifted two feet involves 4 foot-pounds.

In raising a basket of clothes weighing 20 lbs. to a height of 3 feet, 20 × 3 or 60 foot-pounds of work are involved. To raise a kilogram to a height of 4 meters involves 4 kilogram-meters or 400,000 gram-centimeters of work. If the force acts in another direction than upwards, as in the case of pulling the same basket across the floor, then the force required to overcome the friction is multiplied by the distance the basket is pulled. The force in this case is less in magnitude than when the basket is lifted, since friction alone is the opposition to be overcome. This is less than the weight.

In all cases the work done may be calculated by the formula

$$\text{Work (W)} = \text{Force (F)} \times \text{Distance (D)}.$$

In the case of work done in lifting objects, the force is the same as the weight of the object, and the distance it acts is the height the object is lifted. The formula then becomes

$$\text{Work} = \text{Weight} \times \text{Height}.$$

278. Work in Walking. In the act of walking the body is lifted at every step, and as a consequence work is done. The extent of work thus done depends upon how much a person weighs; upon how much he rises on his toes as he walks; and upon how long a stride he takes. A person taking long strides gets more exercise in walking than does another of the same

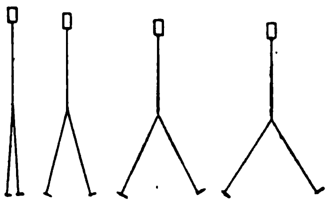


FIG. 252

weight who takes short strides. This is because the body falls farther in the middle of a long stride than it does in the middle of a short one. Figure 252 shows the relation between the drop of the body in the two instances.

QUESTIONS AND PROBLEMS

1. Explain, from the standpoint of work, why, when hanging wet clothes on the line to dry, it is less tiring if the basket holding them is first placed upon a stool rather than upon the ground.

2. Why is it harder to walk upstairs with a load than on the level?

3. A man weighs 180 lbs. How much work must he do to go up to the next floor which is 10 ft. above the floor where he is?

4. A woman rises $\frac{3}{4}$ in. at every step. Her step is 18 in. long. She weighs 130 lbs. How much work does she do in walking 1 mile?

5. Which requires the greater amount of work; the lifting of a 10-lb. pail full of water 15 ft. up from the surface of the water in a well, or the carrying of this water into a house, the floor of which is 4 ft. above the ground? Explain.

MECHANICS OF SOLIDS

279. Downward Pressure Exerted by Solids. Every object has in a given locality a definite weight. The downward pressure resulting from this weight may, however, produce quite different effects under different conditions. If we walk upon a

board placed upon a muddy sidewalk, the board does not sink into the mud nearly so much as one's feet would if there were no board upon which to walk. The same force is acting in both instances, *i. e.*, the weight of the body. The difference lies in the fact that if we are walking upon the board, this weight is distributed over a large area, with the result that on a surface under the board equal to that of the bottom of our shoes, there is only a small portion of the total pressure. It is for the same reason that we do not sink deeply into the snow when we wear snowshoes. The *intensity of the pressure* is what determines the effect on the surface pressed upon. This idea of *pressure intensity,* or pressure per unit of surface, as contrasted with *total pressure,* or pressure on the whole surface, should be thoroughly fixed in the mind; for it is pressure intensity that is nearly always meant whenever pressure is expressed.

280. Balanced and Unbalanced Forces. When two persons pull on a rope in opposite directions there will be no resulting motion as long as both pull equally. The two forces are *balanced.* When, however, one pulls a little harder than the other, motion results in the direction of the greater pull. The two forces are *unbalanced.* All about us are conditions of balanced and unbalanced forces. When things are at rest the former condition exists, and whenever things are moving we know that there is an unbalanced condition. All changes are the result of unbalanced forces.

Questions

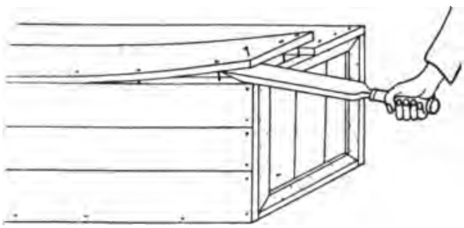
1. Why do women and children as a rule require smaller snowshoes than do men?

2. In which case will there be greater pressure intensity upon the table: when ten equal sized blocks are piled one upon the other, or when they are spread out over the table?

3. In the above question (2) will there be any difference in the pressure of the four legs of the table upon the floor? Explain.

4. Why can a person crawl over thin ice with greater safety than when walking upon it?

281. Machines. There are many things that cannot possibly be done with the hands, such as pulling a nail from a box, chopping meat, grinding coffee, sawing wood. We must resort to some contrivance to aid us. Even when it is possible to do the



a

b

FIG. 253.—SIMPLE LEVERS

work with the hands, we can often do it more advantageously with some implement, to which we give the name of *machine*. If we wish to take the cover off a box, the easiest way is to pry it up with a chisel (Fig. 253*a*). The claw of the hammer makes it possible to pull out a nail (Fig. 253*b*). In these instances the simplest form of a machine, known as the *lever,* is being used. If we wish to get a barrel into a wagon, it requires less effort to roll it up a plank than to lift it directly, just as it is easier to walk up a long gradual flight of stairs than it is to climb a ladder to reach the second floor of a house. In this latter instance we are

using the second general type of machines, called *inclined planes.* Of the first type there are three classes, known as *simple lever, crank and axle,* and *pulley;* to the second type belong the *inclined plane, wedge,* and *screw.* Every tool or implement in the house involves one of these two principles, the lever or the inclined

Fig. 254.—Examples of Simple Machines

plane. As examples of the simple lever we have the can opener, grass clippers, and tack lifter; of the crank and axle we have the bread mixer and coffee grinder; of the pulley the wheels over which the supporting ropes pass as a window moves up or down in its frame (see Fig. 268). An example of the simple inclined plane is found in a plank one end of which is higher than the other, or in a sloping road. The knife edge, axe, and

chisel are wedges; while the meat press and rotary meat cutter are examples of the screw. In Figure 254 may be found illustrations of the different classes of machines.

Machines also enable us to employ other forces than human, such as in the case of a wagon pulled by a horse, the electric motor in the trolley car, the steam engine, the gasoline engine in automobiles. In all of these instances we find at least one, and generally several types of the simple machines represented. These are called *compound machines.*

282. The Lever. In the lever in its simplest form (Fig. 255) we find a force (F) acting upon the machine, which in turn acts upon the resisting body (R). Here the lever is between the acting force and its opposition. If F produces motion, R is moved the opposite way and the various parts of the lever move, with the exception of one point (O). It is about this point O that rotation takes place. O is called the *fulcrum,* which remains stationary. We have thus two forces pulling in one direction and a third force acting between them and in the opposite direction. Let us support a meter stick at its middle point O (Fig. 256) by means of the clamp and the spring balance. Let us place movable clamps, A and B, on either side of O and note the reading of the balance. This shows the downward pull of the meter stick and clamps. Let us now place a 100 g. weight on A and a 50 g. weight on B. If we place B at the 10 cm. mark, we find that A must be placed at the 70 cm. mark to produce equilibrium. The force F_1 acting upon B is one-half as great as the force F_2 acting upon A. The distance B O, however, is

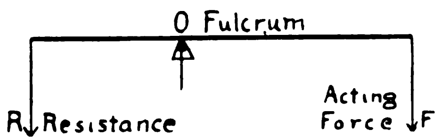


FIG. 255.—SIMPLE LEVER

twice as great as the distance $A\ O$. It is immaterial which of the two forces is called the acting force and which the resisting force.

With the two weights 100 g. and 50 g. on A and B, the reading of the balance becomes 150 g. more than it was at first.

No matter where A is placed with reference to the fulcrum O, B will always be twice as far from O to produce equilibrium, as long as the force on A is twice as great as that on B. If a

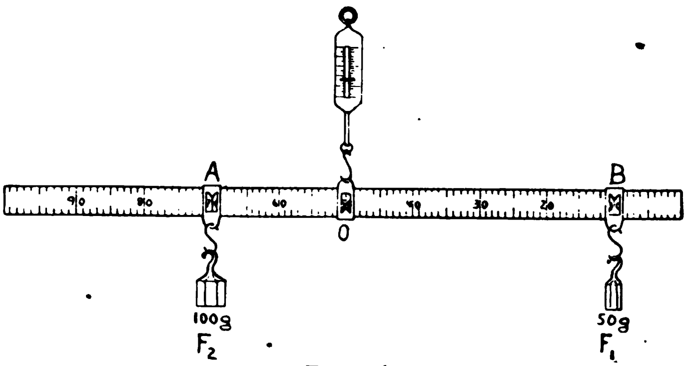


FIG. 256

25 g. weight is placed on B instead of the 50 g., then the distance $B\ O$ must be four times as long as $A\ O$, to produce equilibrium. The balance now reads 125 g. more than at first. In all cases the product of one force and the distance from the fulcrum to its point of application is equal to the product of the other force and its distance. Furthermore, the single force recorded by the balance, which is counteracting the other two and pulling in the opposite direction, is equal to their sum.

283. Rotational Effect of a Force—Moment. If in prying off the cover of a box with an iron bar or a chisel we take hold farther away from the fulcrum, we find that it takes less force

to push down that end. The effect of the force in producing rotation about the fulcrum thus increases as its distance from the fulcrum becomes greater.

To get the maximum effect at any given distance from the fulcrum, the acting force should be applied at right angles to the bar. If it is applied at a slant, then only a part of it is producing a rotational effect; the other part of it acts along the length of the bar, either pushing it inwards or pulling it outwards. In calculating the rotational effect, the perpendicular

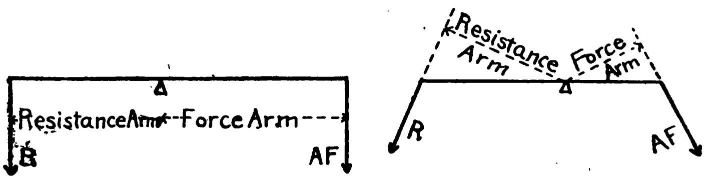


FIG. 257

distance from the axis or fulcrum to the line of direction in which the force acts is what is used. This is called the *force arm* (Fig. 257). The product of the acting force and this force arm is called the *moment of the acting force.* Likewise the product of the resistance and the resistance arm is the moment of the resistance.

Moments that tend to produce rotation like the motion of the clock hands are called *positive,* and contrary to them, *negative moments.* When the positive and negative moments are equal, no rotation results. Thus, in order to cause changes with a machine like the lever, the acting force must produce a moment slightly greater than does the resistance. For purposes of discussion, however, the law of the lever may be expressed as

Acting force $\times$ force arm $=$ Resistance $\times$ resistance arm.

If a force of 20 lbs. acts upon the bar *A O B* at the point *B* (Fig. 258), until the bar reaches the position *A′ O B′*, then while *B* has moved through 6 inches the weight of 80 pounds at *A* has been raised only $\frac{1}{4}$ of 6 inches, or $1\frac{1}{2}$ inches. Since *B* is 4 times as far from the axis *O* as is *A*, and the force needed at *B*, to move 80 lbs. at *A*, is only $\frac{1}{4}$ as great, it must act through 4 times the distance that the 80 lbs. is moved. The work ex-

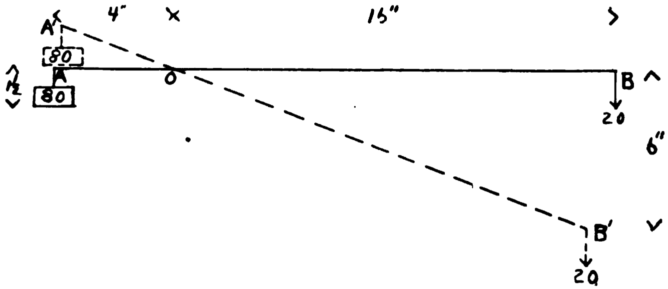


FIG. 258

pended upon the lever by the force of 20 lbs. at *B* (20×6) is practically equal to the work done by the lever, $(80 \times 1\frac{1}{2})$; but, owing to friction at the fulcrum, it is slightly greater, so that we never get from a machine as much as we put into it. For purposes of discussion the general law of machines is *force times the distance it acts is equal to the resistance times the distance it is overcome.* F $\times$ Fd = R $\times$ Rd.

284. Types of Levers. It is easy to see that any one of the three forces may be made the fulcrum of a lever. There are three ways in which this may be done, which give us the three types of levers (Fig. 259). One of the forces always acts in opposition to the other two, with its point of application between them, and it is equal to their sum. In all cases A F $\times$ arm = R $\times$ arm.

In Case I of the first type

$3AF = 30 \times 2 \qquad AF = 20$ lbs.

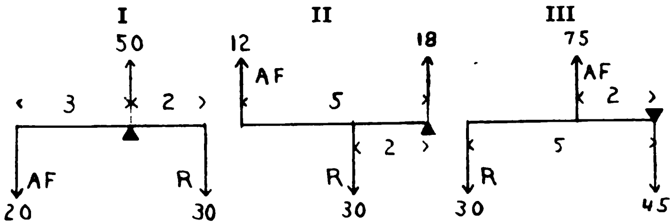
In Case II of the second type

$5AF = 30 \times 2 \qquad AF = 12$ lbs.

In Case III of the third type

$2AF = 30 \times 5 \qquad AF = 75$ lbs.

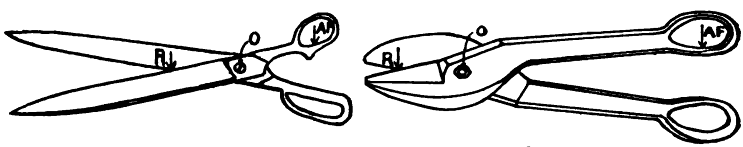
In Case I the fulcrum, which does not move, pushes with a force of 50 lbs. in opposition to both acting force and resistance. In Case II it exerts 18 lbs. in the same direction as the acting



First Type Second Type Third Type

FIG. 259.—LEVERS OF THE THREE TYPES

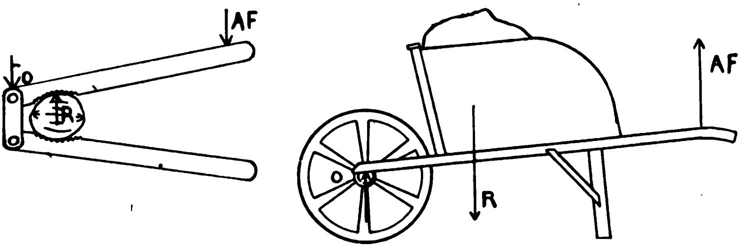
force, and in Case III it exerts 45 lbs. in the same direction as the resistance. The arms are always measured from the fulcrum. In the first type of lever the resistance may be less or more than the acting force; in the second type it is always more; in the third it is always less. We find examples of the first type of lever in the ordinary shears and in the metal cutting shears (Fig. 260). The second type is represented by the nutcracker



a *b*

FIG. 260.—LEVERS OF THE FIRST TYPE
(*a*) PAPER CUTTING SHEARS, (*b*) METAL CUTTING SHEARS

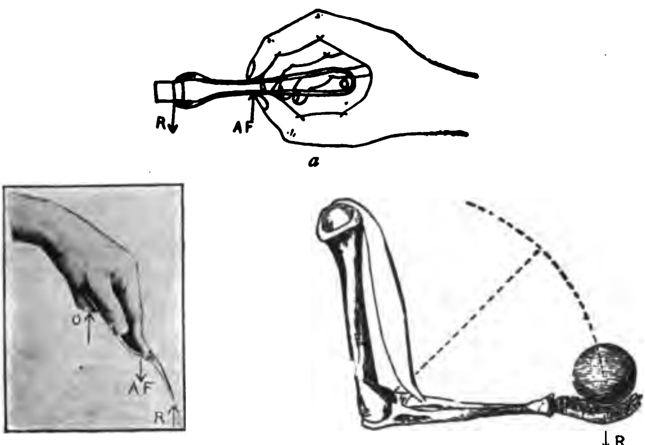
and the wheelbarrow (Fig. 261). A pair of sugar tongs, a table fork as used for meat, the lifting of a weight with the



a *b*

FIG. 261.—LEVERS OF THE SECOND TYPE, (*a*) NUTCRACKER, (*b*) WHEELBARROW

hand outstretched, represent the third type (Fig. 262). In the treadle of the sewing machine (Fig. 263) a first and a third type lever are used in order as the heel and toe alternately press upon the treadle.



b *c*

FIG. 262.—LEVERS OF THE THIRD TYPE, (*a*) SUGAR TONGS, (*b*) FORK, (*c*) FOREARM

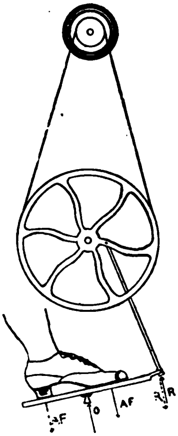


FIG. 263

285. Balances—Platform Scales. There are two types of weighing scales in general use (Fig. 264). In one, (*a*), the arms are of equal length; the object to be weighed is placed upon one pan and weights equal to it are placed upon the other pan. Such a method of weighing is called counterbalancing. In the second type, (*b*), there is one pan; and a weight is moved back and forth on a graduated beam until balance is secured, when the weight of the object is read from the graduated beam. On the left side of the fulcrum the length of the arm remains always the same, and the weight (force) changes. On the right side the movable weight remains the same, but the length of the arm changes. In the steelyard (Fig. 265) we have an example of this type. Steelyards

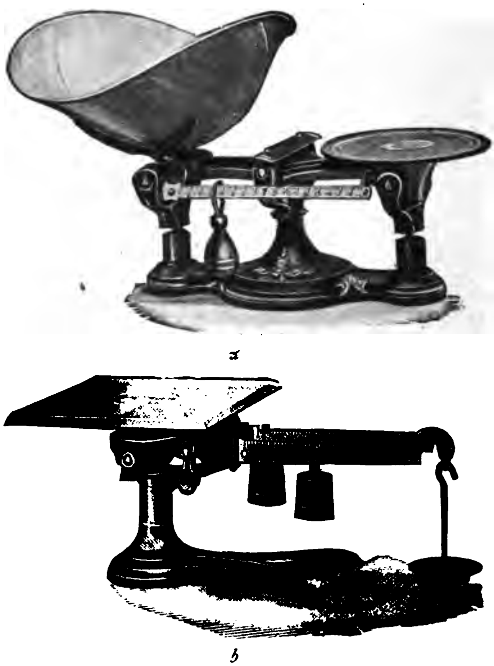


FIG. 264.—PLATFORM SCALES

are frequently used by ragmen, in meat stores, and on a large scale are used for weighing bales in government warehouses.

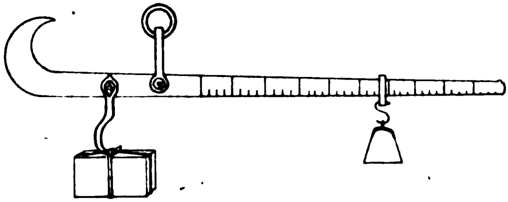


FIG. 265.—STEELYARD

286. Crank and Axle. In the crank and axle, and the pulley, we have a case of a continuous lever. In the windlass (Fig. 266) used for winding clotheslines, the acting force is applied at the handle and the resistance is on the hub or drum.

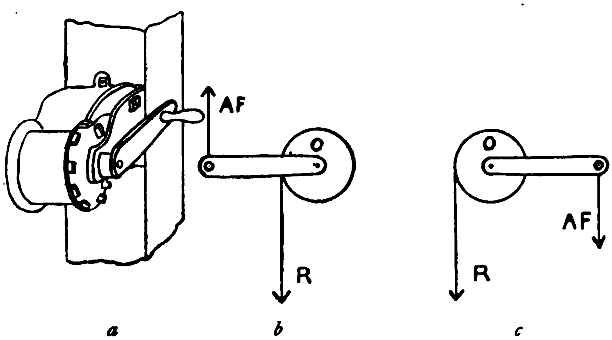


FIG. 266.—(*a*) WINDLASS, (*b*) SECOND TYPE LEVER ACTION, (*c*) FIRST TYPE LEVER ACTION

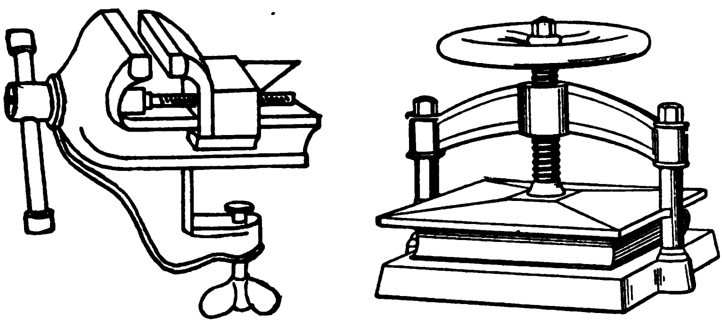
We may have a first or second type action, alternately as the rope is wound up on the side of the hub opposite or next to the handle. The relation between the magnitude of the acting force and of the resistance is the same either way. The gear

of a clothes wringer, ice cream freezer, or egg beater (Fig. 267) are examples of crank and axle. In the driving mechanism of the sewing machine (Fig. 263) and of the grindstone (Fig. 267) there is found a combination of lever and crank and axle.

FIG. 267.—EXAMPLES OF CRANK AND AXLE

287. Efficiency of Machines. There is always a certain amount of friction between the moving parts of a machine. The object sought in the development of modern machines is to reduce as much as possible the loss that is due to friction between the parts. The relation between the work done *by* a machine and the work expended *in running* it determines what is called the *efficiency* of a machine.

288. Screw. In this machine, as exemplified in the vise and the letter press (Fig. 268), the object sought is one of greatly increased pressure. The acting force passes through a considerable distance, while the resistance is overcome through a short distance. When the handle of the vise or the letter press is turned once, the screw advances the distance between two successive threads. This distance is called the *pitch* of the screw-



a *b*

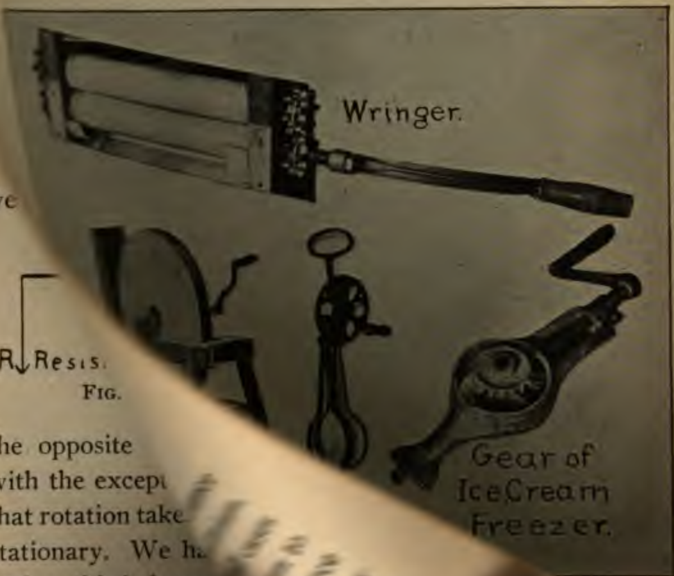
FIG. 268.—EXAMPLES OF THE SCREW, (*a*) VISE, (*b*) LETTER PRESS

thread. The distance the acting force moves is the circumference of a circle. This is considerable as compared with the pitch of the screw, so that whatever force is applied to the handle is greatly multiplied.

The loss due to friction in a screw is much larger than in any other type of machine, as the resistance acts over a considerable surface of the screw thread.

289. Why Machines Are Used—Mechanical Advantage. Since there is always a certain amount of waste work in a machine, due to the friction between the parts, the question may well be asked, Why are they used at all? This may be answered by the one word—convenience.

of a clothes wringer, ice cream freezer, or egg beater (Fig. 267) are examples of crank and axle. In the driving mechanism of the sewing machine (Fig. 263) and of the grindstone (Fig. 267) there is found a combination of lever and crank and axle.



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288. Screw. [illegible] the letter press (Fig. 268) [illegible] increased pressure. The acting force [illegible] able distance, while the resistance is [illegible] distance. When the handle of the [illegible] turned once, the screw advances the distance [illegible] cessive threads. This distance is called the [illegible]

FIG. 268.—EXAMPLES OF THE SCREW [illegible]

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Sometimes a force greater than can be applied directly by the hands is desired; as when we cut metal, crack nuts, grind coffee, squeeze juice from fruit or meat, clamp two glued boards together, raise heavy weights, such as safes or pianos. Sometimes great speed is desired, as in the bicycle, sewing machine, knife grinder. Sometimes we can call upon other forces than muscular, as in the gasoline engine, the electric motor, the water motor, the windmill, the weights of a window (Fig. 269).

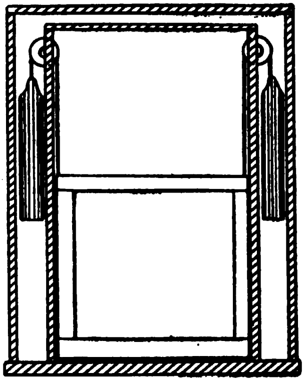


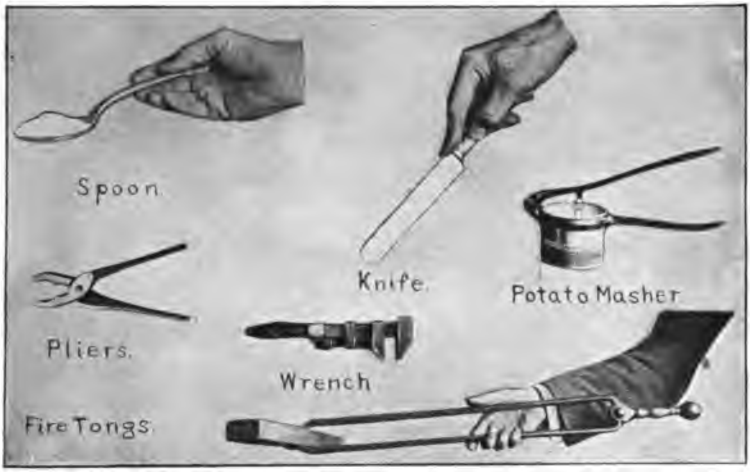
FIG. 269.—THE WEIGHTS HELP TO RAISE THE WINDOW

If we wish to overcome a large resistance, we make the force arm long and the resistance arm short; as in the nutcracker, metal cutting shears, the coffee grinder, and the fruit press. If the force arm is three times as long as the resistance arm, then the resistance overcome will be three times as great as the acting force.

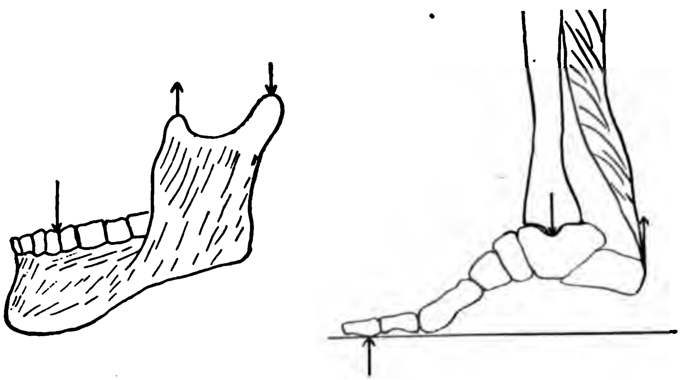
If, on the other hand, we wish greater speed than can be attained directly with the hands, we make the force arm short and the resistance arm long; as in the paper cutting shears, the sewing machine, and the grindstone. If the resistance arm is three times as long as the acting force arm, then the resistance will be moved through three times as great a distance as the acting force moves. The intensity of the resistance will, however, be only one-third as great as that of the acting force.

The ratio that expresses the gain, whether it be in force intensity or in speed, is called the *mechanical advantage* of the machine.

In all cases the work expended equals work done by the machine plus waste work. The less the waste work becomes, the more nearly does the work done by the machine approach the work expended, and the greater becomes the efficiency of the machine.



a



b

FIG. 270.—LEVERS

Questions and Problems

1. Classify as first, second, or third type of lever the following articles: curling iron, spoon, knife when used for spreading butter, fire tongs, furnace shaker, trunk lid, pliers, wrench, potato masher (Fig. 270*a*), jaw of human being, foot when we rise on the toes (Fig. 270*b*).

2. In the seesaw or teeter board, what type of lever do we find? Where must the heavier person sit? How is the up and down motion secured?

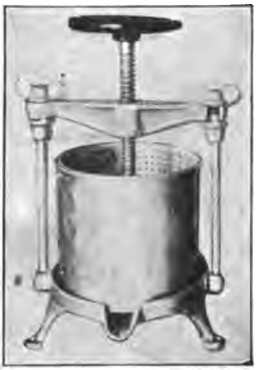


Fig. 270c.—Fruit Press

3. What type of machine appears in the screw driver, knob of a door, the cutting edge of a knife, paper clip, broom, glove stretcher, carpenter's plane, gimlet, needle, shovel used for lifting coal, bicycle, carpet sweeper, flour sifter, fruit press (Fig. 270*c*).

4. Name all the different forms of simple machines you can find in the action of the Yale lock (Fig. 271); the lawn mower; the door lock and latch (Fig. 272).

5. What is the mechanical advantage sought in each of the cases in Questions 1, 3, and 4?

Fig. 271.—A Yale Lock

6. How heavy must each window weight be in order to hold up a window that weighs 25 lbs.?

7. State how you could weigh a 40-lb. piece of ice upon two 25-lb. balances.

8. How much strain must each of the four ropes of a porch swing be able to bear if four persons weighing 160 lbs. each are to sit in it?

9. If a hammock is fastened to two small trees, explain the effect produced upon the trees if some one sits in the hammock.

FIG. 272.—DOOR LOCK AND LATCH

10. Does a machine lessen labor by making it "easier" to do anything? Explain.

290. Center of Gravity. We have learned that all objects when taken above the earth show by their downward pressure a tendency to return to the surface of the earth. If we remove the ground from under them, as in digging a hole, they will drop into this. There thus seems to be an attraction deeper than the surface. Furthermore, a box resting on end on the earth will, if tilted sufficiently, fall over on its side. A person will fall over if he loses his balance. We infer then that the attraction between the earth and objects is between a certain part of the earth and of the object. This point in an object upon which the force of gravity seems to act is called the *center of gravity.* We shall see that the center of gravity of any object tends to get as near the center of the earth as possible. This condition

is reached in the case of any object lying upon the surface of the earth when the center of gravity of the object is as low as possible.

When a weight is held by a string, the string hangs in a *vertical* or *plumb line*. If a pin is put successively through the holes *A, B, C,* of a card (Fig. 273*a*), the card will assume different positions and the plumb line from the pin will pass successively along the lines *A A′, B B′, C C′*. All three of these

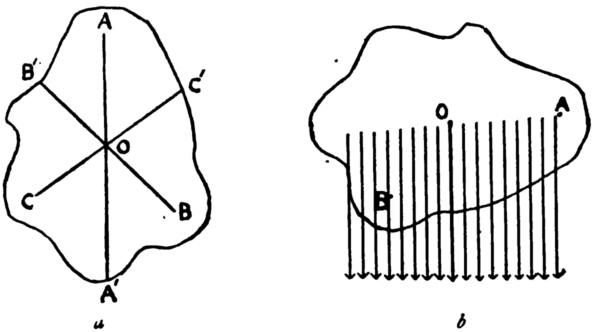


FIG. 273

lines pass through *O*. If the pin is placed through *O*, the card will remain in any position to which it is turned. We may look at any object as made up of many particles, all of which are pulled downwards by gravity. When the pin is placed through *A*, these combined forces (Fig. 273*b*) act to produce negative rotation about *A*. When the pin passes through *B*, positive rotation results. When *O* is the point used, there are as many forces acting to produce positive, as to produce negative rotation. In other words, *O* is the point of application of the single force that takes the place of all the forces of gravity on the object. The pin acts upwards against this, and the two forces being equal and opposite, no motion results. The plumb line

which connects the center of gravity of an object with the center of earth is called the *line of direction.* In solid objects that are uniform in shape, like the cube, rectangular block, or sphere, the center of gravity is at the same point as the geometrical center. If the objects are not symmetrical or are made up of different materials, it will lie near the heavier part. In some instances the center of gravity lies in space outside of the material part of the object, as in the case of a ring, stool, box, or bottle. Sometimes it may lie much below the support; as in the pendulum of the clock.

291. **Equilibrium—Stability.** A mucilage bottle "stays put" much better than a salt shaker (Fig. 274). A person standing with feet spread apart is much more difficult to push over than one with heels together. It is much easier for a child to walk when she can take hold of something to keep her balance. Balance and resulting ***equilibrium*** and ***stability*** depend upon the extent of support the object has.

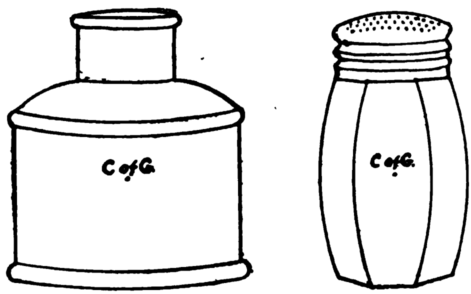


FIG. 274.—MUCILAGE BOTTLE, SALT SHAKER

The area formed by the lines connecting the points of support of any object is called its *base.* Thus the base of a chair is nearly a square; of a table it is a rectangle, square, or triangle; of a three-legged stool it is a triangle; of a bicycle when being ridden it is a broad line connecting the points where the front and back tires rest on the ground; of a sphere it is almost a point; of a cylindrical pencil on its broad end it is a circle, on

its side a straight line, and on its sharpened end a point. It is very easily seen that if the line of direction passes through the base, equilibrium results. To illustrate this, take the toy called the leaning tower (Fig. 275). As long as the top is off, the center of gravity of the remainder is at *C* and the line of direction passes between *a* and *b*. When the top is put on, the center of gravity of the whole tower is at *D*, so that it topples over, as the line of direction falls outside of *ab* and negative rotation results. In the case of the leaning tower of Pisa (Fig. 93), the line of direction falls well within the base. When a person leans over or raises one foot forward without at the same time moving the upper part of the body backward, his center of gravity is thrown forward and a fall will result if the foot is not put upon the ground in order to change his base so that the line of direction passes within it. The act of walking is a series of falls thus checked. A person must always lean forward considerably when he starts to run.

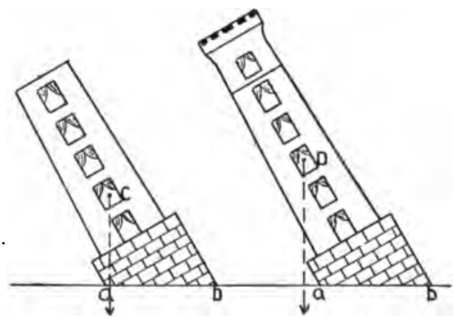
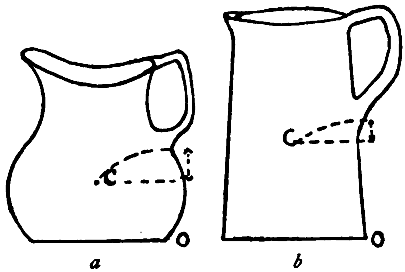


FIG. 275.—LEANING TOWER

The stability of anything, which determines its tendency to upset, depends upon how much work must be done to get its center of gravity to a point where, when released, it will of its own accord fall to a lower position. If the line of direction already passes outside of the base the object will need no force to aid it in falling. Such a condition exists in the case of a lead pencil on its point. The object is in an *unstable* condition. In

all feats of balancing performed by jugglers, the performer's skill is shown in his ability to keep the base under the center of gravity of the articles he supports. While apparently in equilibrium, the objects are really in a very unstable condition.

Of the two pitchers (Fig. 276), weighing the same, the first will be the more difficult to tip over, as the center of gravity is lower and must therefore be raised through a greater height as it is tilted about *O* to the position, where it will fall over. Objects with low center of gravity and broad base are the most stable. For this reason lamps are generally made with the lower part heavy. An object is called "top heavy" and is easily upset when the center of gravity is very high.



a b

FIG. 276.—(*a*) IS MORE STABLE THAN (*b*)

Aged and infirm people use canes to support them when they walk, as the cane acts like a third foot to increase the area of the base. If a person is carrying a pail of water in the right hand, he must lean to the left, as the pail of water throws the center of gravity of the body and the pail of water together over to the right, thereby decreasing the stability of his body, the base of which remains the same.

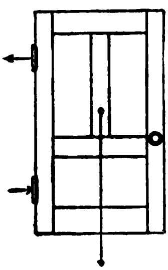


FIG. 277

292. Sagging of Doors. Doors are usually supported by two hinges, on the side, one near the top and the other near the bottom. The weight of the door acts downwards at its center of gravity (Fig. 277). The upper hinge must

pull inwards. The lower hinge must push outwards. For this reason it is more important to have the upper hinge securely fastened to the framework. In the same way, the upper screw of a wall bracket should be the more secure.

The rotational downward effect produced by the weight of the door at the center of gravity tends to produce a sagging of the outer edge (Fig. 278*a*). This makes the diagonal *a b* from the top of the hinged side to the bottom of the latch side longer than the other diagonal *c d*. To prevent this sagging, a brace in the form of a strip of metal should be fastened across the diagonal *a b* that increases in length, so as to prevent this pulling apart of the corners. This sagging effect is particularly likely with long gates. To prevent it, sometimes the end next the hinges is made higher and a piece of board is nailed diagonally, as shown in Figure 278*b*. Sometimes a heavy piece of wood is inserted between the other two corners, as in Figure 278*c*. This wooden bar prevents compression as well as gives solidity to the gate.

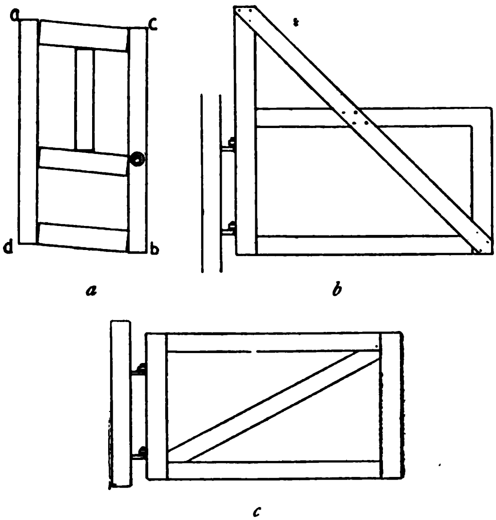


FIG. 278

293. **Pendulum.** The pendulum, as used in clocks to control

the movement of the clock works, is familiar to us all. In this we have a weight or bob at the lower end of a slender rod. The center of gravity is much below the base. When the bob is pulled aside the center of gravity is raised, so that when the bob is released it falls back to its lowest position. It does not, however, stop there, but, because of inertia, passes on, rising on the other side. As a result a to and fro motion takes place. This vibrating motion will gradually become less, and finally come to an end because of friction at the support and the resistance of the air as the pendulum moves through it. If, however, this frictional retarding effect is overcome by the force of the escapement wheel (Fig. 279), the pendulum continues to vibrate as long as the energy of the coiled spring or raised weight in the clock is communicated to the teeth of the wheel. As the pendulum swings, the teeth of the wheel press alternately upon the right and left sides of the rocker at the top of the pendulum, thus giving a slight push to the pendulum.

FIG. 279.—CLOCK WORKS


FIG. 280 MERCURY PENDULUM

Long pendulums vibrate much more slowly than do short ones. A pendulum one-fourth as long as another will vibrate twice as many times per minute as will the longer one. The size or weight of the pendulum bob makes no difference in the rate of vibration.

In the mercury form of compensated pendulum, seen so

often in mantel clocks, there are in the bob two tubes (Fig. 280) which contain mercury. As the center of gravity is lowered by the expanding rod, the expansion of the mercury upwards counteracts the effect. The pendulum thus remains the same length at all temperatures.

Questions

1. Why are mucilage and ink bottles cone-shaped and with bottoms of thick glass?

2. Why is it easier to move a barrel by rolling than by tipping it end over end?

3. Why does an egg roll over on its side when we place it on end?

4. Why are life preservers placed near the armpits?

5. What is the danger in standing up in a canoe or rowboat? Explain.

6. Which one of the three possible positions in which a brick may be placed is most stable? Give reasons.

7. Why is a tricycle less likely to upset than is a bicycle?

8. Why is it easier to carry a heavy suit case than a valise of the same weight?

9. Why are the legs of a stepladder spread apart?

10. Why do we fall over forward when we try to pick up a pin by bending over, standing with the heels against the wall of a room?

11. In what manner do we keep our balance when we try to pick up anything from the floor?

12. Why do we sometimes put sand in tall flower vases?

13. Why are the Japanese flower stands, as used to hold individual flowers on the table, made of lead?

MECHANICS OF LIQUIDS

294. Pressure in Liquids. In houses where the water supplied to the boiler comes from a tank upstairs, the hot water comes from the faucet in the kitchen with much more force than from the faucets upstairs. This is evidence that the higher the column of water extends above the outlet, the greater is the pressure at the outlet. Pressure in liquids increases with the depth below the surface exposed to the air. This may be easily demonstrated by means of a Mariotte's bottle from which the lowest stream is pushed out farthest (Fig. 281). If now bent tubes are inserted in the holes (Fig. 282), the water level will be the same in the bottle and in the three tubes. (*Note.*—As a matter of fact, it will be slightly higher in the tubes because of capillarity, which will be discussed later.) If there is an opening in one of the tubes anywhere below the level shown, water will run out of that tube until its level in the bottle and in the other tubes has reached

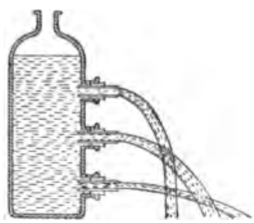


FIG. 281

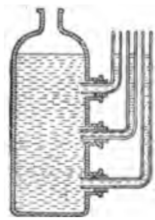


FIG. 282

FIG. 283.—THE HEIGHT OF THE WATER IS THE SAME, IRRESPECTIVE OF THE SHAPE OR SIZE OF THE TUBE

that of the opening. The saying, "Water seeks its level," is well illustrated by Figure 283. In the teapot (Fig. 284) and the watering pot we can tell while pouring how much water is left in each without looking inside.

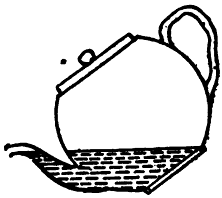


FIG. 284

If into a tube one centimeter on a side (one centimeter square) (Fig. 285), water is poured to a depth of one centimeter, there will be a pressure of one gram on the bottom, which has an area of one square centimeter. If the column of water is 2 centimeters high, the pressure becomes 2 grams per square centimeter. For each additional centimeter in the height of the column, there is one gram pressure added to the square centimeter on the bottom.

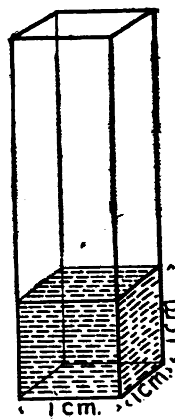


FIG. 285

If we now take a tube one centimeter by 2 centimeters on its base, there will be a pressure of 2 grams on 2 square centimeters when water is poured in to a depth of one centimeter. The pressure per square centimeter is the same as before, namely, one gram. For each additional centimeter of height in the water column there will be an additional 2 grams pressure on 2 square centimeters of the base, or one gram on one square centimeter of the base. Thus an increase in the area of the base does not increase the *pressure intensity*. This is determined only by the *height* of the water column. The *total* pressure upon the base is, however, affected by the area of the base. It is found by multiplying the pressure per square centimeter by the area in square centimeters. If the depth is in feet and the

area is in square feet, the pressure intensity is 62.4 pounds per square foot for every foot of depth below the surface.

If a box 30 cm. long and 20 cm. wide is filled with water to a depth of 15 cm., the pressure intensity on the bottom is 15 g. per sq. cm. The total pressure is 15 multiplied by the area, which is 30×20. The total pressure is thus $15 \times 30 \times 20 = 9{,}000$ g. If a box is 2 ft. long and 1.5 ft. wide, and is filled with water to a depth of 2 ft., the pressure intensity is $2 \times 62.4 = 124.8$ lbs. per sq. ft. The total pressure is $124.8 \times 2 \times 1.5 = 374.4$ lbs.

295. Density. A jug filled with kerosene or alcohol weighs less, and when filled with molasses it weighs more than when filled with water. An iron ball weighs many times as much as a cork ball of the same size. Aluminum utensils are noticeable for their lightness. We thus see that equal volumes of different substances weigh differently. The *weight of any unit volume of a substance,* such as a cubic foot or a cubic centimeter, is called the *density* of that particular substance. It is expressed in the English system in pounds per cubic foot and in the metric system in grams per cubic centimeter. It is found by dividing the weight of any given object by its volume.

Following is a table of the densities of many common substances.

In grams per cubic centimeter

Aluminum,	2.67	Copper,	8.8
Beeswax,	.96	Cork,	.24
Brass,	8.4	Diamond,	3.5
Butter,	.94	Earth,	1.5–2
Camphor,	.98	Ebony,	1.18

Glass,	2.5–3.5	Alcohol,	.82
Gold,	19.36	Benzene,	.72
Graphite,	2.5	Blood,	1.06
Human body,	.89	Ether,	.74
Ice,	.91	Glycerin,	1.26
Iron,	7.7	Mercury,	13.6
Ivory,	1.82	Milk,	1.03
Lead,	11.4	Molasses,	1.42
Lignum-vitæ,	1.33	Naphtha,	.84
Limestone,	3.18	Olive oil,	.92
Paraffin,	.8–.9	Turpentine,	.89
Platinum,	21.5	Vinegar,	1.02
Silver,	10.4	Water,	1.00
Sulphur,	2.0	Sea water,	1.026
Wood,	.5–.8	Air,	.001293
Zinc,	7.00	Hydrogen,	.000089

296. Pressure Intensity When Liquids Other Than Water Are Used. If a liquid one cubic centimeter of which weighs twice as much as water were used in a tube, the pressure would be twice as much as at the same depth in water. A liquid less dense than water would produce a less pressure intensity. Consequently in calculating the total pressure produced by a liquid upon any horizontal surface, we must know the *density* of the liquid, the *depth below the surface,* and the *area pressed upon.* The total pressure is the product of these three. For example, at a depth of 5 meters in fresh water the total pressure on the top of an immersed box 2 meters long by one meter wide will be $500 \times 200 \times 100 = 10{,}000{,}000$ g. In sea water, which has a density of 1.026 g. per c.c., the total pressure at the same depth on the same box top is $500 \times 200 \times 100 \times 1.026 = 10{,}260{,}000$ g.

In a tank of kerosene oil of density .8 g. per c.c., the total pressure on this box top at a depth of 5 meters is $500 \times 200 \times 100 \times .8 = 8{,}000{,}000$ g.

297. Meaning of Depth in a Liquid. In determining the depth it is the *vertical,* not the *slant,* distance from the surface exposed to the air, to the point under consideration, that must be taken. The pressure at the bottom of tube *A* (Fig. 286) is just the same as at the bottom of *B,* though the length of column *A* is greater.

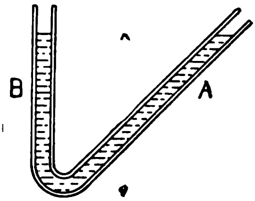


FIG. 286

298. Pressure at a Given Point in a Liquid Is the Same in All Directions. Assuming that the downward pressure at the point *O* in the liquid (Fig. 287) is 5 g. per sq. cm., then there is an equal upward and an equal sideways pressure towards the front, back, and sides. Were this not true and if the sideways pressure at *X* were greater than at *O,* there would be an unbalanced force, and motion would result. For the same reason motion downwards would result if the upward pressure at *O* were less than the downward pressure there. Likewise there would be motion upwards if the upward pressure at *O* were greater than the downward pressure there.

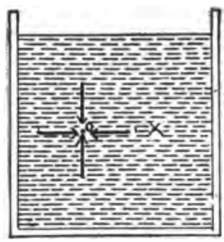


FIG. 287

QUESTIONS

1. Why are water tanks placed high up in the house?

2. Must the walls of a deep water tank be any stronger near the bottom than near the top? Explain.

3. On the Great Lakes, large empty corked bottles are sometimes weighted and lowered over the sides of ships to a considerable depth. When they are pulled up they are full of cold water. Explain.

4. What will happen if an incandescent lamp bulb is broken under water? Explain.

5. Why doesn't water rise to any extent inside a tumbler when the tumbler is pushed mouth downwards into a jar of water?

6. A cubic foot of water weighs 62.4 lbs. Ice is .91 as dense as water. About how large is a cake of ice that weighs 50 lbs.?

299. Buoyant Effect in Liquids. A swimmer feels a certain lifting effect of the water when he is swimming. It is easier to lift stones in water than on land. Some substances like cork, oil, and wood float when thrown upon the water; others like iron and other metals sink in the water. Let us suppose that the cube, the side view of which is shown by Figure 288, is suspended in the water. The cube is 4 cm. on an edge and its top is one centimeter below the surface. The downward pressure on the top will be one gram per sq. cm., or 16 g. total, the area being 16 sq. cm. The upward pressure per sq. cm. on the bottom will be 5 g., with a total pressure of $5 \times 16 = 80$ g. The sideways pressure on the front will equal that on the back, and the pressures on the sides will balance. We thus see that there is an excess pressure of $80 - 16 = 64$ g. upwards on the bottom. This tends to make the body rise. If the weight of the cube, which is producing a downwards pres-

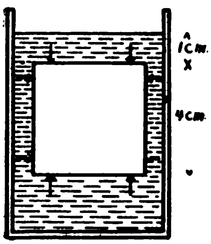


FIG. 288

sure, is greater than this, the cube will sink; if it is less, the cube will be pushed up and float; if it is the same, the cube will remain where it is, when released from its suspended condition. Which of these three things will happen is determined by the material of which the cube is made. The volume of the cube is 64 c.c., exactly equal to the volume of water it displaces. The buoyant effect is 64 g., exactly equal to the weight of water displaced. If the density of the material is less than one gram per c.c., the total weight will be less than 64 g. and the cube will rise. If its density is one gram per c.c., it will remain suspended; if more than one gram per c.c., it will sink.

The quantitative relation between the weight of water displaced by an object and the buoyant effect produced upon it by the water may be shown by the following experiment:

Fill the overflow can *A* (Fig. 289) with water, allowing the water to run out until it reaches the level of the outlet *O*. Next weigh the catch bucket *B* empty. Take any object such as a piece of marble, that

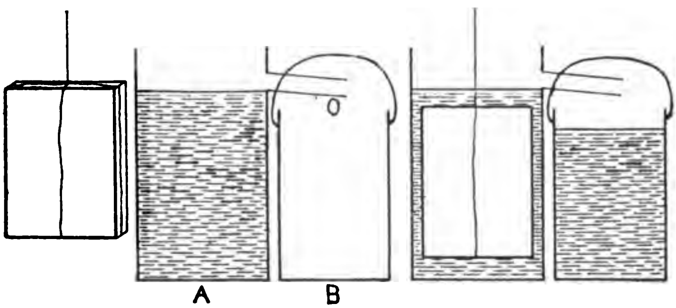


FIG. 289

sinks in water, and weigh it in air by counterbalancing. Next carefully lower this into the water of the overflow can. The water will be displaced, and the amount pushed up will be equal to the volume of the marble. This water will overflow into the catch bucket. Weigh the marble in the water, thus finding its apparent weight in the water.

Weigh the catch bucket with the displaced water, that has overflowed. If we subtract the apparent weight of the marble in water from its weight in air, and the weight of the catch bucket empty from its weight with the overflow water, we find the two results are equal. From this we deduce Archimedes' principle, which is that the loss in apparent weight of an object immersed in a liquid is equal to the weight of liquid displaced.

Whether a substance sinks or floats when immersed in a liquid depends upon whether or not its weight is greater or less than an equal volume of the liquid, *i. e.*, whether or not it is denser or less dense than the liquid. A substance such as ice will float in water but will sink in alcohol, because it is denser than alcohol and less dense than water. If mercury, olive oil, and colored water are mixed and allowed to stand, they will separate into layers, with the mercury on the bottom and the oil on top.

Sometimes objects float even when made of materials denser than the liquid. Ships float even though made of steel; a tin cracker box, if placed carefully upon the water, so as to allow no water to get inside, floats. The explanation of this is that while the cracker box is floating upon the water, and therefore apparently weighs nothing, the space that *was* occupied by the displaced water is *now* occupied, not by the cracker box alone, but by cracker box and air within it (Fig. 290). Now the weight of the whole cracker box and of the air included in the space *a b c d* is just equal to that of the displaced water that occupied the space *e f g h*. If water is poured inside the box, the latter will settle lower into the water until the weight of the tin box + the water inside is greater than that of the displaced

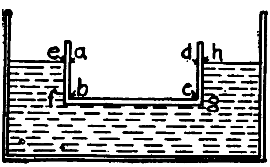


FIG. 290

water, when the box will sink. This is why metal rowboats or metal ships sink when they are "swamped," while wooden boats do not. It explains why a motor boat, with its heavy engine, sinks when filled with water, even though its framework is made of wood.

Pumice is full of very small pores. The air in these is not readily forced out when the piece of pumice is placed in water. Pumice full of air thus floats upon water, though its substance is denser than water. Certain soaps float upon water because of a large amount of air in them.

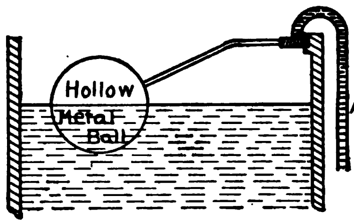


FIG. 291

In the ball cock that regulates the supply of water in house tanks, the float is a hollow metal ball (Fig. 291). As the water level rises the buoyant force pushes the ball up, thus stopping the flow of water by shutting the valve.

Questions

1. Why does the water rise in a bathtub when a person gets into it?

2. Is the buoyant effect of water different at different depths? Explain.

3. Does a jar of water with a goldfish in it weigh any differently from the same jar of water without the fish? Explain.

4. Explain why any soap floats which in the process of manufacture has been beaten while it cooled.

5. A ship passes from salt into fresh water. Will it sink lower or rise in the water?

6. Why is it easier to float on water if our lungs are filled with air?

7. Why does cream in milk rise to the top?

8. Explain the use of life preservers.

MECHANICS OF GASES

300. Gases Have Weight. Gases have weight, just as do liquids. This may be easily shown by weighing the brass globe (Fig. 292), which is at first filled with air. If it is again weighed after pumping out the air, there will be a difference in weight equal to the weight of the air removed.

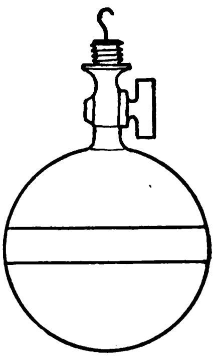


FIG. 292

301. Atmosphere. Just as sea animals crawl about on the bottom of an ocean of water, so do human beings and animals move about at the bottom of an ocean of air called the *atmosphere*. This atmosphere forms a blanket of air about the earth, extending upwards to a height of about fifty miles. People have been led to believe this because balloonists find that the air becomes less and less dense (rarer or thinner) as they go higher, and from this the probable height of the atmosphere is calculated. Beyond the limit of the atmosphere there is nothing but the ether.

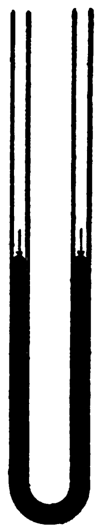


FIG. 293

302. Pressure of the Atmosphere. The atmosphere above the earth exerts a downward pressure, just as do liquids. How great the pressure is depends,

of course, upon the depth of the air column. If a U-tube (Fig. 293) has mercury in the two arms, its upper level will be at the same height in both, as there must be the same pressure exerted at the bottom of each side to produce equilibrium. The atmosphere in this case pushes down equally on each side. Suppose, however, that one side is sealed at the top and the closed arm is filled with mercury and then inverted (Fig. 294). If the closed arm is over thirty inches long the mercury will not come to rest at the same level in both arms, as in Figure 293, but will drop only slightly, leaving a space *V* in which there is no air or mercury. Such a condition, in which a space contains neither solid, liquid, nor gas, we have learned is a vacuum. The mercury does not fall further because something is holding it up. Inasmuch as there is equilibrium, the pressure at the bottom of the two arms must be equal. On the left side there is a pressure produced by the long column of mercury *A*; on the right there is a pressure produced by the short column of mercury *B* and the atmosphere. The atmosphere does not act upon the left side. If the top of this side were opened, the air would immediately get in and acting downwards upon the top of the mercury column, force it down until the level is the same in both arms. In Figure 294 the atmosphere is exerting a pressure equal to the column *D*, since *B* is balancing *C*. We thus say that the atmosphere exerts a pressure equal to that of a column of mercury about 30 inches in height. The pressure exerted by the atmosphere is thus equal to about 15 pounds to the square inch, or 1,033 grams per sq. cm. Con-

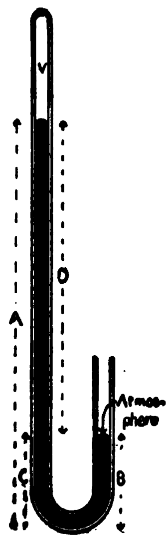


FIG. 294

sidering the size of a square inch it is easy to see that the pressure of the atmosphere upon our bodies and upon objects about us is enormous.

303. Barometers. An apparatus used for the measurement of atmospheric pressure is called a *barometer*. There are two kinds of barometers, *mercurial* (Fig. 295) and *aneroid*. The latter type will be explained later. In either one, the reading that records the atmospheric pressure is given as so many inches or centimeters. The barometric reading is not the same at all times, as the pressure is different from day to day. Cooks say that water does not "come to a boil" so quickly on some days as on others. This is because on a day when the atmospheric pressure is greater than normal, the boiling point of water is higher, as there is a greater pressure of air to be pushed aside by the steam (see Section 49).

FIG. 295
MERCURIAL BAROMETER

304. Atmospheric Pressure as a Weather Indicator. It is a well-known fact that when water boils away in a kettle more rapidly than usual, it is an indication of stormy weather. The sea captain foretells a storm by a rapid fall in the barometer readings. Both of these means of predicting a coming storm are due to the same cause, a reduced atmospheric pressure.

Wind is air in motion, resulting from a difference in the pressure of the atmosphere in two different places. The air always moves from the place of higher to that of lower pressure. Rain clouds are blown along by the wind. They are thus brought to those regions where the atmospheric pressure has been reduced in some way. A considerable "fall" in the barom-

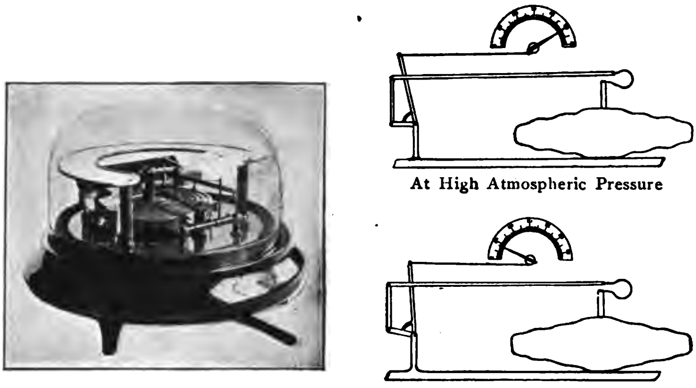
eter shows to the sea captain a pressure lower than normal, and warns him of the coming storm. A pressure lower than normal makes water boil at a lower temperature and therefore it boils away faster.

A rapid "rise" in the barometer indicates an increased atmospheric pressure, which results in storm clouds moving away. Thus fair weather is predicted when the barometer rises.

305. Relation between the Volume of a Gas and Its Pressure. When we ride on a bicycle or in an automobile we feel the jolts less because the tires are filled with air. This air is not in the same condition as ordinary atmospheric air, but has been forced in until it is at considerable pressure. It has been compressed. The tire, before the air was pumped in, was full of air; it remains full of air as we pump more in. The difference is that it contains the *same* volume of air but at a *different* pressure; and it is this increased pressure that keeps the tires from flattening out. Large volumes of outside air at ordinary pressure have been forced to occupy a small volume at greatly increased pressure. The volume of this air decreases at the same rate that its pressure increases. This law applies to all gases the temperature of which remains the same. It was discovered by Robert Boyle, and is called Boyle's Law of Gases. If the pressure upon a gas is made equal to two atmospheres it will occupy one-half the space that it occupied at ordinary atmospheric pressure. Likewise if we compress a gas to one-third of its original volume, it will exert three times as much pressure outward.

306. Aneroid Barometer. In the aneroid barometer (Fig. 296*a*), which is the more common form seen, the changes in atmospheric pressure make the walls of the hollow corrugated metal box (Fig. 296*b*) separate or come closer together. The

box is air-tight and the air inside is in a rarefied condition. This air will increase in volume as the pressure outside decreases, and will push the thin walls of the box apart. One side of this box



a *b*

FIG. 296.—ANEROID BAROMETER

is fastened securely to the base of the instrument. The other side is connected to a pointer through a system of levers. As the free side of the box moves up and down with the changes in volume of the air inside, the pointer moves back and forth over a scale on which is graduated the inches or centimeters by which the pressure is indicated. Sometimes the pointer is an inked pen that records upon paper wound around a revolving drum a curve which represents the fluctuations of pressure for a week. This is called a *recording* barometer.

FIG. 297

307. Examples of the Action of Atmospheric Pressure. A tumbler filled

with water may be turned upside down, provided a card is first placed snugly over the top (Fig. 297). If the faucet of a kerosene can is turned on, only a small amount of oil will come

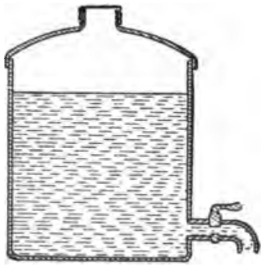


FIG. 298

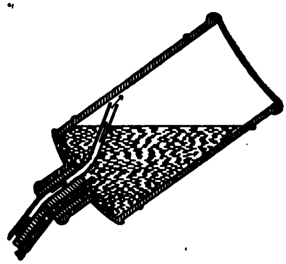


FIG. 299.—INK POURER

out, if the cap is not unscrewed to allow the atmosphere to act upon the top of the oil (Fig. 298). It is very difficult to pour a liquid, such as ink, from a small necked bottle without considerable spattering, as air must get inside to push down on the top of the ink and force it out. This action causes gurgling. To prevent this in ink bottles and to get a steady, even flow, patent stoppers are sometimes inserted in the neck of the bottle (Fig. 299). The air passes in through the tube and the ink passes out through the lower hole. In the drinking fountain (Fig. 300) water comes out only a little at a time and bubbles of air rise in the bottle to take its place. In all of these instances the atmospheric pressure is either greater or equal to the combined pressure of the expanded air and of the liquid inside the jars.

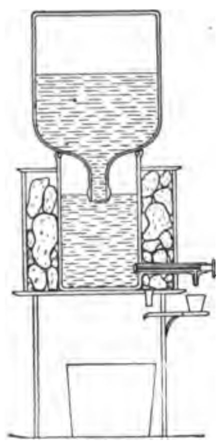


FIG. 300.—DRINKING FOUNTAIN

308. Bunsen Burner and Sprayer. Whenever anything moves rapidly through the air it compresses the air immediately ahead of it and creates a partial vacuum behind it. The result of this is a rush of air from all sides into the space behind the object. We have all experienced the "suction" produced by a train moving at high speed by a station; leaves and dust are "drawn" along by fast moving automobiles. This action applies not only to solid objects but to liquids and to gases also. In the Bunsen burner as used in the Welsbach light and gas stove (Fig. 301), the illuminating gas passes through a small opening into a larger tube with air vents on the side. The partial vacuum created by the rush of a small stream of gas causes air to rush into the tube through the side openings, there to be swept along and mixed with the gas and thus to make more

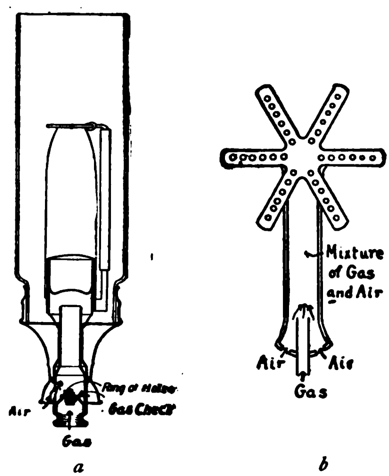


FIG. 301.—BUNSEN BURNER EFFECT (*a*) WELSBACH LAMP, (*b*) GAS STOVE

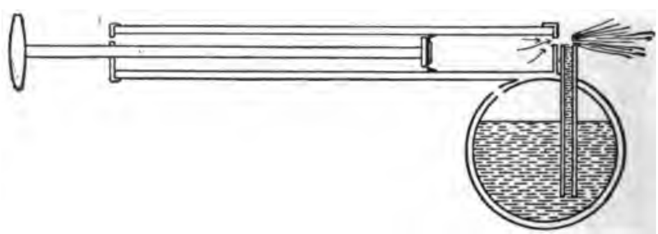


FIG. 302

complete combustion. The mixture, when it reaches the outlet at the top, gives the bluish flame characteristic of this form of burner.

In the sprayer (Fig. 302), a small stream of air is forced over the end of a tube, the other end of which rests in the liquid to be sprayed. The reduced pressure at the open end of the tube is such that the atmosphere forces the liquid up the tube, where it is blown away in the form of fine particles.

309. Ventilator. In this (Fig. 303) the wind passing outside of the cone creates a partial vacuum inside so that the air is forced up from below. Ventilators of this sort are used sometimes to create a better draft in chimney flues. They take the place of taller chimneys.

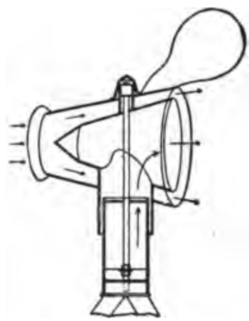
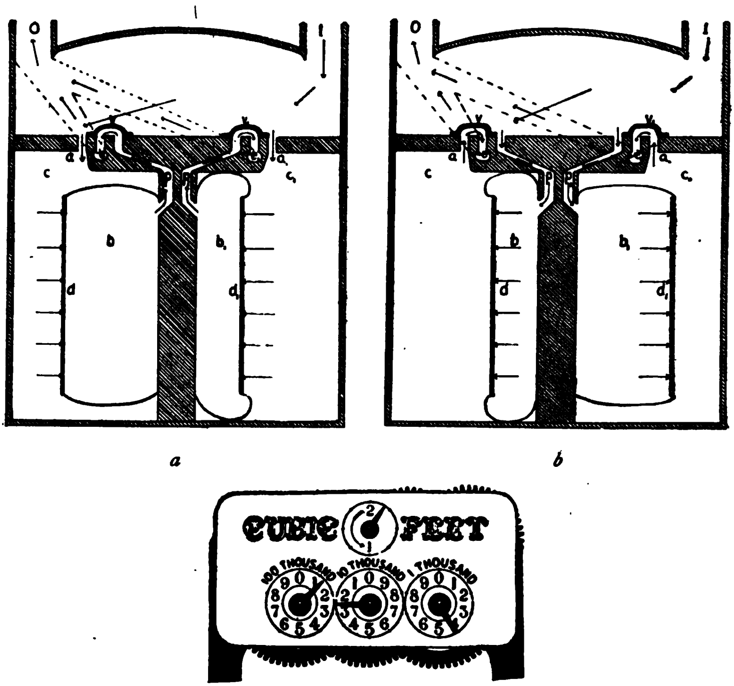


FIG. 303.—VENTILATOR

310. Gas Meter. Illuminating gas as supplied in houses comes from the street main at a pressure slightly greater than that of the atmosphere. The problem of measuring the amount of gas used in a house without interfering with the steady flow at the burners, is solved in the type of meter illustrated in Figure 304*a* and 304*b*. The gas from the supply pipe enters the meter through I and passes through openings a and a_1 into chambers c and c_1 (Fig. 304*a*). The pressure of the gas is sufficient to force the diaphragms d and d_1 inwards. The gas or air already in chambers b and b_1 is forced out through p and p_1 into passageways e and e_1, which unite to form the outlet O to the house pipes. As the diaphragms d and d_1 move inwards a lever operated by this movement causes the slide valves v and v_1 to move the opposite way. When d_1 has moved

as far as possible inwards, the slide valve v_1 no longer connects p_1 and e_1, but it connects a_1 and e_1, leaving p_1 open to the gas from I. The gas entering b_1 forces d_1 outward (Fig. 304*b*), and



a *b*

c **Gas Meter Dial. It reads 12,400 cubic feet**

FIG. 304.—GAS METER

the gas in c_1 is forced out through a_1 and e_1 into the outlet O. When d_1 is half way out, d is as far inward as it can go; valve v now connects a and e, and gas enters b through p, while the gas in c is forced out through a and e.

A steady flow of gas through O is obtained because b and

b_1 are not empty at the same time. The back and forth movements of the diaphragms are recorded through a system of levers connected to a clockwork device, on the dials of which the number of cubic feet of gas that pass through the meter may be read (Fig. 304*c*).

Questions and Problems

1. A liter of air weighs 1.293 g. Calculate the weight in grams of the air in a room 5 meters long, 4 meters wide, and 3 meters high.

2. What is the weight in pounds of the air in the room of Question 1?

3. Find the dimensions of your classroom, and calculate the weight of the air in it in pounds.

4. Why is it that sometimes when a person enters a room where the doors open inwards, the opening of one door causes another to shut?

5. Describe a simple method of emptying a large bottle of water quickly, and without gurgling or spattering.

6. Explain why the waste pipe "pump" used by the plumbers often removes a stoppage in the sink waste pipe. This consists of a bell-shaped piece of rubber, fastened to a stick. It is pushed up and down over the outlet of the sink.

7. Why are pop-overs or cake in an oven likely to fall if the oven door is shut violently?

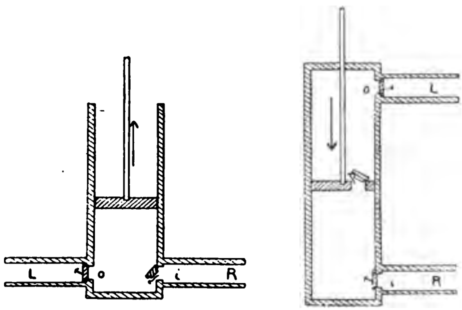
8. Why is a gas meter more likely to register too little rather than too much as it becomes worn with usage?

PUMPS

311. During our study we have had occasion to refer to two kinds of pumps, in both cases dealing with air. In Section 49, Figure 19, reference was made to an air exhaust pump as used to make water boil at reduced pressure. In Section 296 a pump was mentioned as used to force air into a bicycle tire.

312. **Air Pump.** Pumps are contrivances used to transfer fluids (liquids or gases) from one place to another. They consist of some movable part and a confined space of some sort for the fluid to occupy temporarily.

If the piston (Fig. 305*a*) is raised, the air below it expands. Its pressure becomes less, and as a result the atmosphere pushes upon the two valves *o* and *i* harder than the air inside pushes outwards. Each valve opens only one way, *o* outwards and *i* inwards. The greater atmospheric pressure acting upon *o* shuts it, while on the other side *i* is forced open and air rushes in until the inside and outside air pressures are equal.



a *b*

FIG. 305.—AIR PUMP

On the down stroke of the piston the reverse process takes place. The air is compressed and pushes outwards harder than the atmosphere pushes inwards. Valve *i* is forced shut and valve *o* is opened, the air passing out until the pressures inside and outside are equal.

We thus have a transfer of air from the right to the left of the cylinder as a result of the up and down stroke of the piston. If we connect the side *L* to the rubber bladder of a basket ball or football, air will be forced into it under pressure, and the basket ball becomes harder. In this way the pump becomes a *compression* air pump, forcing air into the basket ball on the *down stroke.*

If, on the other hand, we connect the side *R* to a bottle, the air in the bottle will expand and pass into the cylinder below the piston on the up stroke, because, as the piston moves upwards, the air below it expands and exerts a less pressure upon *i* than does the air in the bottle. This will take place on the *up stroke* of the piston. On the down stroke the air below the piston is forced out through *o* and *L*. On each up stroke the air in the bottle tends to expand into the cylinder of the pump, just as long as there is a sufficient difference in pressure to force open the valve *i*. In this case, in which air is being removed, the pump becomes an *exhaust* pump.

Frequently the outlet is on the other side of the piston from the inlet, and there is a valve in the piston to allow the air to pass through it on the down stroke and be forced out on the up stroke (Fig. 305*b*).

The various *vacuum cleaners* in use nowadays are exhaust pumps of either the to and fro piston, or of the rotary type. In the latter form there is a fan (Fig. 306) which, as it rotates, forms a partial vacuum at *a*. This is because of the centrifugal tendency of the air between the sides of the wheel. If the openings *a* and *b* are covered, and *a* is connected to the floor by a pipe, while *b* is connected to a bag of closely woven cloth, the air, as it is forced into *a* by the greater outside pressure, will carry dust along with it. This dust is then collected by the bag as the air rushes through.

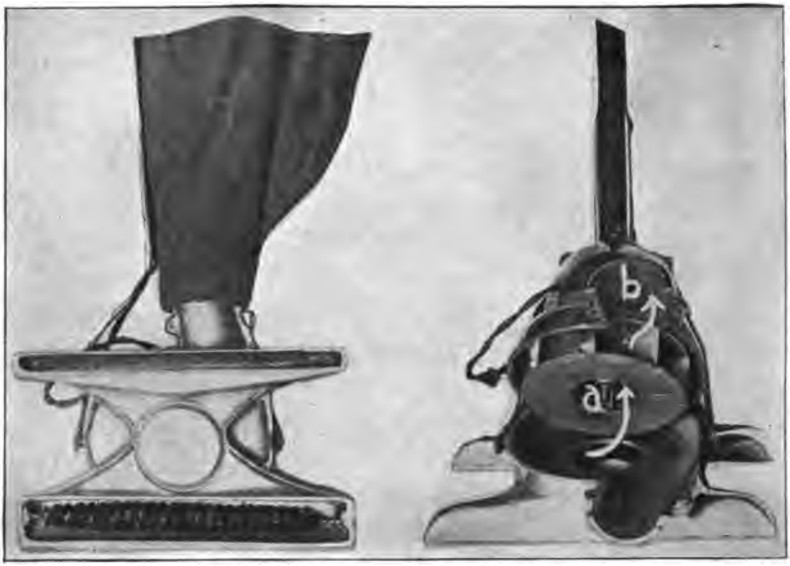


FIG. 306.—CENTRIFUGAL VACUUM CLEANER

313. Fire Bellows. In the common fire bellows, as the two sides *A* and *B* (Fig. 307) are pulled apart, the air pressure inside becomes less than that of the atmosphere outside and the valve *e* is opened by the air pushing in. The nozzle *o* is so small that very little air can get in through it in comparison with what comes through the valve. When the sides are pushed together, the inside air pressure becomes greater than that of

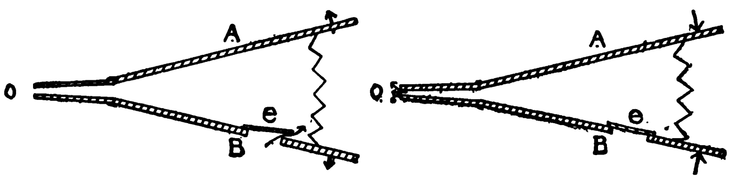


FIG. 307.—FIRE BELLOWS

the atmosphere and shuts the valve *e*. The air is thus forced out the nozzle *o* onto the fire.

314. Human Lungs. In the lungs we have a bellows in which the inlet and outlet for the air are the same. The lungs are made up of two connected sacs inclosed within the chest cavity. Between the outer walls of the sacs and the inner walls of the chest cavity there is a thin layer of lubricating liquid. The atmospheric pressure keeps the sacs inflated so that they fill the cavity. By means of the muscles between the ribs and by the diaphragm it is possible to increase the size of the chest cavity. (*Note.*—The diaphragm separates the chest cavity from the abdomen.) During this act of *inspiration* the air inside, upon expanding, becomes reduced in pressure and the greater atmospheric pressure outside forces air in. On expiration, the muscles are relaxed, whereupon the chest contracts naturally and the air pressure inside becomes greater than the atmospheric pressure outside. The air is forced out by the diaphragm and by the muscles of the chest. The greater effort is in the act of inspiration, for it is in this that the chest muscles are stretched. Figure 308 represents the action of the diaphragm. A toy balloon is fastened to a glass tube, and the tube is passed through a one-holed stopper that fits the top of the bell jar. Over the lower opening of the bell jar is tied a rubber disc. If the disc is pulled

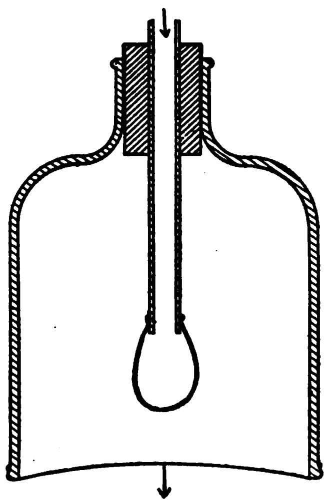


FIG. 308.—ACTION OF DIAPHRAGM IN THE HUMAN BODY

downwards the balloon becomes inflated. If the disc is pushed inwards the balloon collapses. (*Note.*—After the rubber disc has been fastened over the lower end of the bell jar, the balloon should be blown up slightly before the stopper is inserted.)

315. Pneumatic Piano Player. In this apparatus we find application of an exhaust pump in the form of a bellows operated by foot power. The piano mechanism is the same as in any regular piano. There is an additional mechanism (Fig. 309) by means of which the hammers of the piano can be made to strike the wires through atmospheric pressure instead of by the pressure of the hand. Which hammers shall strike is determined by perforated paper rolls which pass across a tracker bar consisting of a series of openings, each one of which corresponds to a note on the piano. The foot bellows produces a partial vacuum in each of these openings as long as they are covered by the paper. When a perforation in the paper passes over the opening, air passes through it into the tube, as indicated by the arrows. This air presses against the three pistons at the left of the three bellows above the piano key, and moves the pistons to the right, thereby allowing the air in the three bellows to be pumped out by the exhaust pump (foot bellows) below. The greater atmospheric pressure on the outside of these three bellows makes them collapse. As they do so, they push up the rod which actuates the hammer mechanism, just as does the

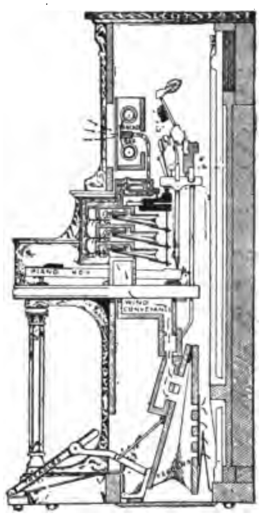


FIG. 309.—PIANO PLAYER MECHANISM

piano key when it is pushed down. The rolls holding the perforated sheets are turned by an air motor that is operated by the same exhaust bellows that operates the hammers.

316. Bicycle Pump. In the bicycle pump (Fig. 310) there is no valve in the piston nor at the outlet. There is a valve in the tire, however. The leather rim of the piston is cup-shaped, curving downwards. On the up stroke the edges curve inwards and air passes around the rim; on the down stroke the leather opens outwards, presses firmly against the wall of the cylinder, and thus prevents the passage of the air around the piston. The action may be likened to the effect produced upon an umbrella when it is pushed back and forth, while being held by the end *away* from the handle. It opens out and shuts according as we push it away or draw it towards us.

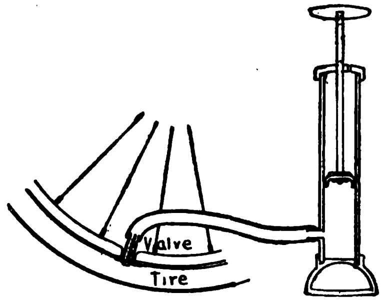


FIG. 310.—BICYCLE PUMP

317. "Suction." What makes water rise in a pump? Our commonly accepted idea of water is that it flows down hill, not up. This is because it is denser than the air and therefore sinks beneath the air. When we put a straw into soda water and "suck" on it, the soda "rises" into the mouth. We have learned that whenever there is motion, an unbalanced force is the cause. Is the air pulling the soda after it, or is something pushing it from behind? More reasonably the latter is the case, for there must

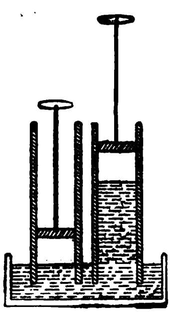


FIG. 311

be something under the water to push it up. What really happens may be explained by Figure 311. If the long tube with its lower end in water has a tight-fitting piston in it (see *a*), the air inside the piston pushes down upon the water inside just as hard as the atmosphere pushes on the water outside, since the water levels are the same. If, however, the piston is raised, the air inside will expand and exert a less pressure. Some water will be pushed up the tube (see *b*) by the unbalanced outside pressure. The water will rise until the combined pressure of the expanded air and the water inside equals this atmospheric pressure. If the piston is now pushed down again, the air will be compressed and will exert an increased downward pressure sufficient to equal the atmospheric pressure without the aid of the water column inside. The water thus drops back to its original position; or even lower if the piston is pushed down so far as to increase the inside air pressure above that of the atmosphere outside. We thus see that it is the pressure of the atmosphere that forces water up the tube when the piston is raised.

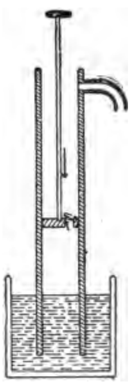


FIG. 312

Suppose the piston has a valve in it (Fig. 312) that will open upwards only. When the piston is raised this valve will remain shut; as the pressure of the atmosphere downwards on the top of it is greater than that of the air upwards inside. If the piston is now pushed down suddenly, the compression of the air below it will take place so quickly that the valve will be forced upward and the air will escape through it into the atmosphere above. There will now be less air in the cylinder than originally. On the next up stroke the water will rise higher inside, as there will be less air inside to press down with the water. A repetition

of the sudden down stroke will let more air out of the top. After several such strokes all the air will be removed and water will begin to come up through the valve, on the down stroke. Once above the valve, the water will be lifted up on every upstroke, just as water is lifted by a bucket, to take the place of the water that flows out the side. This fresh water comes from below, and is pushed up to the valve by the atmosphere at every up stroke.

As above described, there must be a very rapid down stroke; otherwise the water would fall back, and not pass through the

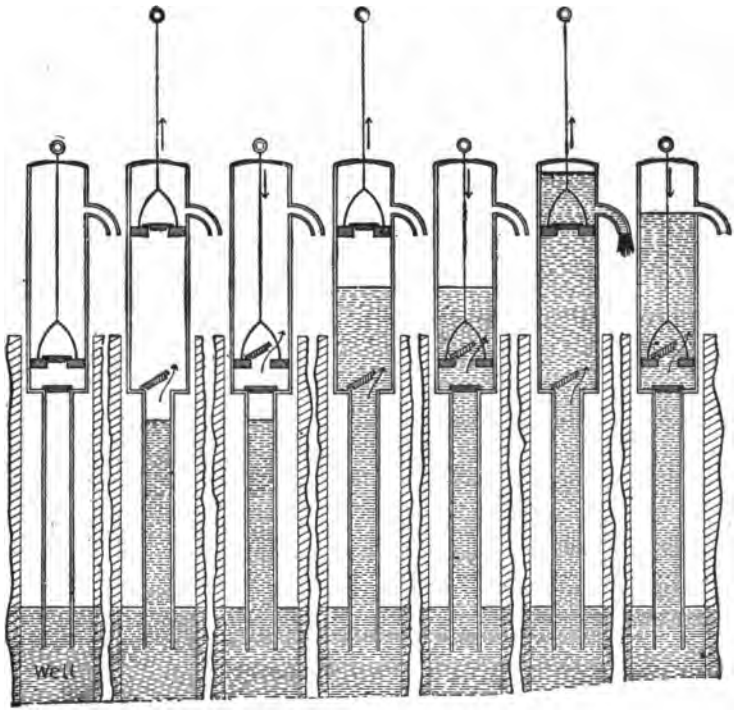


FIG. 313a.—LIFTING PUMP

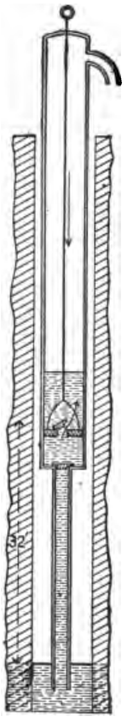


FIG. 313*b* DEEP WELL PUMP

valve in the piston. To prevent this a second valve should be placed in the tube just below the piston at the bottom of the stroke (Fig. 313*a*). This valve opens upwards as does that in the piston. It shuts when the water starts back on the down stroke, so that the water *must* pass through the piston. Such an arrangement gives us what is called a *lifting* or *suction* pump.

318. Limit to the Height Water Can Be Raised by a "Suction" or Lifting Pump. Since the atmosphere can force mercury up 30 inches, as in the barometer, it can force water 30×13.6 times as high, or 408 inches, which is equal to 34 feet.[1]

Thus it can readily be seen that since the water is continually being forced up to the valve of the piston by the atmosphere, the piston at the lower end of the stroke must not be higher than 32 feet above the water in a well, if we are to get it out at the top. For this reason, in very deep wells the piston rod has to be quite long (Fig. 313*b*).

319. Priming a Pump. Sometimes the sides of the piston, which are generally of leather, become dry from lack of use, so that the piston does not touch the walls of the tube all around (Fig. 314). In this case air leaks around the piston as it is raised and lowered. Water must be poured in at the top so as to fill this space while the piston is being moved. The action must of course be quick or the water will soon run down around the piston. Such a process of starting a dried out pump is called "priming." After the leather becomes wet, it swells and the piston fits tightly.

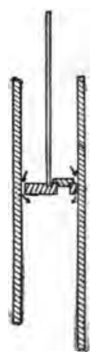


FIG. 314

[1] Since water turns readily to a vapor, so that we cannot get so near a vacuum over it, as with mercury, this height is really less, about 32 feet.

320. Simple Force Pump. If the piston of Figure 313 were solid, and a valve opened outward near the bottom (Fig. 315), we should have a *force* pump, in which water would come out

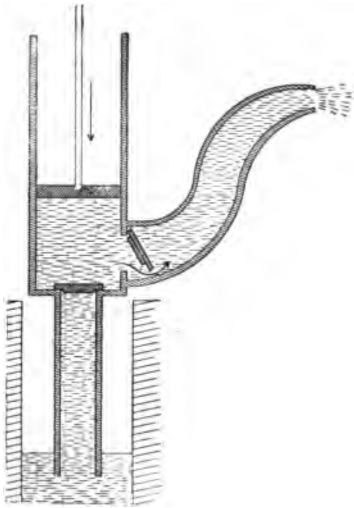


FIG. 315.—SIMPLE FORCE PUMP

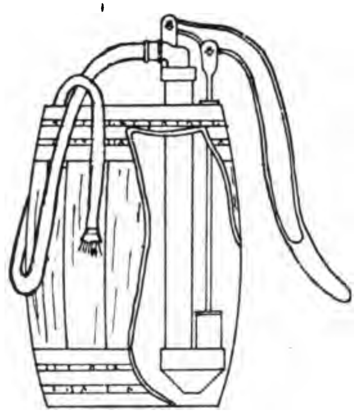


FIG. 316.—TREE SPRAYING PUMP

of the pump, ***not*** on the ***up stroke,*** but on the ***down stroke.*** Such a pump is used for spraying trees (Fig. 316).

321. The Heart a Force Pump. The heart beat, and its accompanying pulse in the arteries, is produced by the most perfect and efficient pump known. The heart is a muscular organ divided vertically into two independent halves, each of which is a force pump. In each half is an auricle and a ventricle. For our purpose the auricle need not be considered, save as it aids the action of the ventricle, the true pump. A simple force pump as above described requires an inlet and an outlet, each fitted with a one-way valve, and a solid piston as a means of

transferring the liquid from inlet to outlet. There is no piston in the heart (Fig. 317), but instead of this there is an expansion and contraction of the walls of the ventricle which make the cavity alternately large and small. On expansion, blood rushes in from the auricle into the ventricle through the auriculo-ventricular valve. The valve into the artery is shut. When the

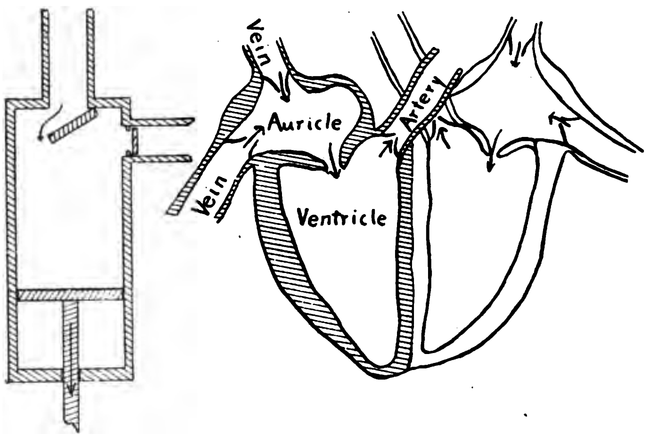


FIG. 317.—HEART ACTION

ventricular walls contract, the auriculo-ventricular valve is forced shut and blood is forced into the artery. The alternate expansion and contraction of the ventricle produce the heart beat; while the intermittent pumping of blood into the artery produces the pulse.

322. Siphon. Many people are often bothered by having the drip pan of the refrigerator overflow. It is practically impossible to remove the pan from under the refrigerator and empty it into the sink, without spilling considerable of the water. A simple little device in the form of a short rubber tube,

about a foot long, properly used, will do away with all this unnecessary spilling. Fill this tube with water, hold the ends tightly to prevent the escape of the water, and release one end under the surface of the water in the pan, allowing the other end to rest on the bottom of a dipper on the floor alongside. Water will flow from the pan to the dipper until the level in the dipper is the same as that in the pan. One or two emptyings of the dipper will bring the water level in the pan to a safe point for removing the whole pan to the sink and emptying it. In this simple rubber tube so used, we have a *siphon*, the action of which may be explained by Figure 318. Whenever forces are unbalanced, motion results. In this case the atmosphere acts equally downwards at *s* and upwards at *o*. The water inside the tube below *i* balances an equal column in the jar of water; the column *i e* balances *e t;* the column *t o* is unbalanced, and pulls downwards and out. Just as long as the outlet *o* is below the level of the water in the jar there will be this unbalanced column, and action results. This action is greater the farther the opening *o* is below the inside level. It must be noted that the atmosphere keeps forcing more water up the arm *i e* as it goes out the arm *e o*. We may thus say that a siphon is a contrivance which utilizes atmospheric pressure to allow us to transfer water from a higher to a lower level, first making it go over an elevation.

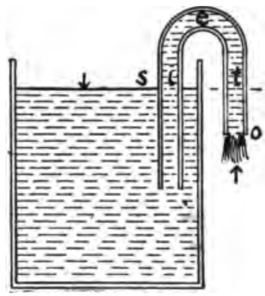


FIG. 318.—SIPHON

323. Adhesion and Cohesion. When we desire to stick together two substances that do not of themselves adhere, we must place between them something that sticks or adheres to

each. Such a substance is called an adhesive, as glue, mucilage, cement. Which one we use depends upon the substances to be treated. For inorganic substances like crockery, glass, stone, we use mineral cement; for organic substances like paper or wood, we use glue or mucilage of organic origin. The reason for this is that the cement must have nearly the same expansion rate as the objects cemented. Otherwise a change in temperature will cause a sliding of one object over the cement. It is on this account that it is difficult to cement inorganic materials like metal or porcelain to organic substances like pasteboard.

The force of attraction between the adhesive and the thing stuck is called *adhesion,* as contrasted with the force that holds different parts of the same substance together, called *cohesion.* Cohesion is exemplified in the opposition that wood offers to being broken or torn apart; that metals offer to being broken; that pieces of cement or glue themselves offer to being fractured. In the case of glue on wood, experience has shown that a thin layer well pressed between the two pieces holds them together much better than a thick layer does. This shows that the adhesive force between wood and glue is greater than the cohesive force in the glue itself. The force of cohesion differs in substances, just as does that of adhesion between different substances. Whether any part of a substance clings to another when the two are brought together depends upon which force is greater. Thus water clings to the skin and feels wet when the finger is immersed. The finger is wet when removed. In the case of mercury, however, though the finger feels wet when immersed, it is dry when removed. Liquids between which the adhesive force is great mix very readily; as in the case of alcohol and water. In the case of oil and water, the oil will not mix and floats upon the surface of the water. Water does not adhere

to oily substances, hence the difficulty in washing oily hands; or in trying to dry hands with unbleached cloth, in which there is considerable gummy substance.

QUESTIONS

1. What is the objection to a fire bellows with no side valve, as in the case of the human lungs?
2. What would happen if the chest walls of the human body were punctured?
3. Of what use is the piston in a pump?
4. Why are there valves in a pump?
5. What would be the result if either of the heart valves failed to act?
6. What evidence is there on a piano player, as seen by the operator, that the pump is of the exhaust type?
7. State three ways in which a lifting and a force pump differ.
8. What must be the condition of the water level in a jar, and of the level of the outlet, in order that a siphon may empty the jar of water?
9. How may we increase the speed with which the water flows from a siphon?

324. Capillarity. A rough porous paper absorbs ink well and is therefore used for blotting paper. In paper which we use for writing purposes, the pores have been filled up with some substance, called a filler, that prevents the spreading of the ink. A lump of sugar with only one corner dipped in a cup of coffee or tea quickly turns brown all through, showing that

the liquid has risen through it. A towel when rubbed on the wet hands becomes wet through. A lamp wick with one end in the oil soon becomes saturated throughout. In all of these instances, the adhesive force has a chance to act over a very large surface. Spreading outwards and upwards, such an action in small openings as are present in porous bodies is called *capillarity*. We see it all about us in the swelling of wood and string in damp weather, in spots spreading on the ceiling when the roof leaks. The great porosity of wool makes it absorb large quantities of water, which require a long time to evaporate.

To prevent capillary action we put a filler in wood and coat it with varnish. This counteracts the tendency of the wood to absorb moisture and warp as a consequence.

Cloth, both woolen and cotton, each of which is easily wet, is frequently made waterproof by putting something into it to prevent capillary action.

In rubber we have a material which in itself is not porous nor does water adhere to it. It therefore makes the best waterproof material.

Questions

1. What force holds powdered graphite together when it is greatly pressed in making the "leads" for lead pencils?

2. Why does a lead pencil make a mark on paper?

3. Why does a slate pencil make a mark on a slate, but not on paper?

4. Explain the soldering of copper and zinc.

5. Explain why two pieces of iron may be welded, while a piece of iron cannot be welded to a piece of brass.

6. Why does soaking shoes in oil make them waterproof?

7. Explain why salt becomes damp.

8. Why does varnish preserve wood?

9. Why are pens slit?

10. Why cannot a towel be wrung dry?

11. Why does a clothes line tighten if left out during a rain storm?

12. Why must wooden tubs and pails be kept damp?

13. Why does flour tend to remove an ink stain if it is applied while the ink is still fresh?

14. Why is it very difficult to remove a kerosene or ink stain from marble?

Review Questions on Mechanics

1. What is the correct way to alight from a street car? Explain.

2. Which will overturn more easily, a wagon with a ton of hay on it, or the same wagon with a ton of iron on it? Explain.

3. Why is it better to have the ice door of a refrigerator in front, rather than on top?

4. What difference does it make, if when you are buying groceries the weighing is done on scales the arms of which are of unequal length?

5. Why is it easier to carry two pails half full of water, one in each hand, than one pail full of water?

6. Why is chalk used for writing on the blackboard?

7. Why may grease or wax spots on cloth often be readily removed by means of a blotter and a hot iron?

8. Why is it difficult to dry the hands with new towels?

9. Why are city water pipes most likely to break at the lowest part?

10. Why does a person lean toward the rear of a street car while it is stopping?

11. Of what type of lever is the pedal of a piano?

12. Why does a lawn mower move more easily if the handle is held down low?

13. Why do door knobs make it easy to open doors?

14. Why are lips put upon pitchers?

15. Why does striking two books together remove the dust from them?

16. In removing dishes from a tray that is balanced by the outstretched fingers, why should dishes be taken first from one side and then from the other side?

17. Why do heavy persons tire quickly when they walk?

18. What types of machines are brought into action when a sod is cut and lifted by means of a spade?

19. Why do we not receive such a jar when we land on our toes as when we land on our heels?

20. Why does a person lean forward in walking up stairs?

21. Why is a pyramid the most stable of all forms of objects?

22. Why does ink come out of a fountain pen when it is shaken?

23. When a window is lifted by the hands, what type of lever is brought into action?

24. Why is it difficult to wash greasy hands?

25. Explain why water leaves a dog's back when he shakes himself after getting wet.

26. Why does the waste material rise to the top, while suet or lard are being "rendered"?

27. Explain how a thread dipping to the bottom of a

tumbler of water and hanging outside upon the table may empty the tumbler.

28. Why must a person walk erect while carrying a large bundle on the head?

29. In weighing with platform balances, does it matter on what part of the pan the object or weights are placed?

30. Why do chains on automobile wheels prevent skidding?

31. Why does a gate shut itself, if the upper hinge extends farther from the support than does the lower hinge?

32. What is the object of using rubber knobs on door jambs?

33. Why is it difficult to walk on stilts?

34. Why does homemade soap float?

35. Why does starch mixed with salt keep the salt from becoming damp?

36. Explain why catgut strings, as used on clock weights, twist in damp weather.

37. Why is the endboard of a wheelbarrow placed as near the wheel as possible?

CHAPTER VII

PLUMBING

Water Supply.
- Ground Water.
  - Open and Driven Well.
- Compression Tank Supply.
- City Water Supply.

Distribution of Water in a House.
- Cold Water Supply.
- Hot Water Supply.
  - Indirect and Direct.
- Closet Tanks.
- Fixtures.

Waste Removal.
- Traps.
  - Venting of Traps.
- Water-Closets.
  - Different Types.
- House Drain Trap.
- Fresh Air Inlet.

Need of Pure Water. Next to an ample provision of uncontaminated air for breathing, nothing is so essential to human life as a supply of pure, wholesome water. This ought to be so abundant that it can be used very freely. Together with this plentiful supply of water, there should be a good plumbing system in a house.

In the country, where houses are scattered, the removal of waste from the house is not a difficult matter, so long as care

is exercised in keeping the waste matter away from the source of water. During drought the water supply, however, is sometimes the cause of considerable worry.

With the rapid growth of cities and the resultant concentration of families, the problem of a pure water supply and a proper sewerage system has been constantly growing. In the cities, where houses are close together, unless the sewerage system is under one general control, there is great danger of contamination of the water, as well as of the air supply. In order to avoid this contamination, certain regulations are made concerning the removal of waste in city houses.

WATER SUPPLY

325. Ground Water. In the country, the water supply comes from wells or springs, the quantity depending upon the rainfall.

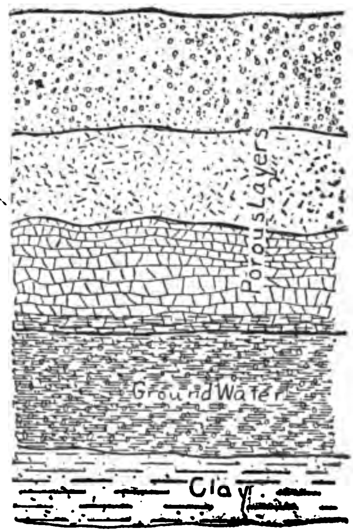


FIG. 319.—GROUND WATER

The crust of the earth is made up of layers of different composition, which have been deposited in ages past, one upon another. Some of these layers, such as sand or gravel, are porous, and allow water to sink readily through them. Other layers, such as clay or rock, are not porous, and water cannot penetrate them. When rain falls upon the surface of the earth, the water soaks into the porous layers, and sinks until it reaches one of these impervious

layers. If this layer is horizontal, the water collects over it to a varying depth, according to the amount of rainfall (Fig. 319). This water is called *ground water.*

In a flat country it will be of the same depth over a large area. In case the layers of earth are uneven (Fig. 320), there may be a layer *b* that is porous and exposed in some place on a mountain side. If *c* and *d* are not porous, water will flow between them and collect until it rises to the level *e* in the layer *b*,

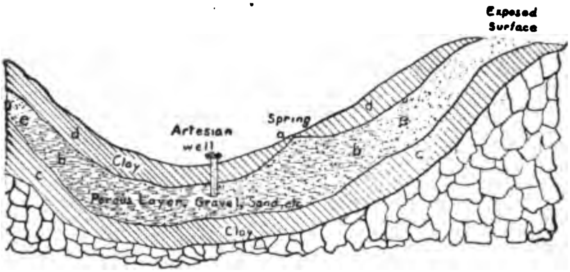


FIG. 320

provided there is no outlet through *d* or *c*. In case the thickness of *d* is very slight at some point, say at *a*, the pressure of the water in *b*, the level of which is much above *a*, may be sufficient to force an opening through *d* to the surface, and a *spring* results.

In case the layer *d* is too thick for the water to work its way through, an artificial opening may be forced through *d*, and an *artesian well* results. Water will be pushed out through the opening by the pressure produced because of the higher level of *e*. This is a *true* artesian well. The term, however, has come to be applied to any well that has been bored *through* a non-porous layer *to* a porous one containing water. The water in all cases is supplied by the rainfall that has collected in the porous layer.

If ground water on a level place is to serve as a water supply, it must be tapped by means of a *well*. This may be an *open* or a *driven* well.

326. Open Well. An open well consists of a hole dug in the ground to a point that is below the upper level of the ground water (Fig. 321). Water tends to pass by capillary action to

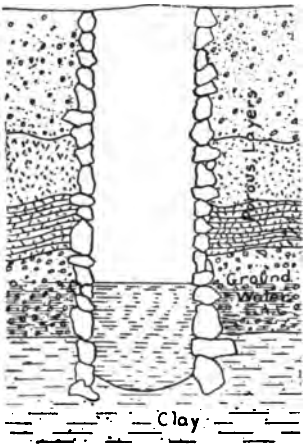


FIG. 321.—OPEN WELL

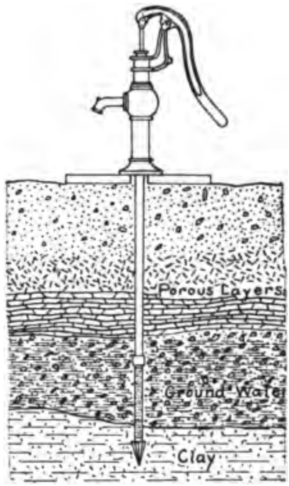


FIG. 322.—DRIVEN WELL

any place exposed to the atmosphere, if the soil is loose. For this reason water from all sides flows into a well, in which the level of the water is the same as that of the surrounding ground water. Water is raised from such a well either by buckets or by means of a lifting or force pump.

327. Driven Well. In this type of well (Fig. 322) an iron tube made in sections, with a point on the lowest one, is driven through the earth until it reaches ground water. The first section of the tube, which has the point on it, is perforated with

many holes, so that the water can pass into it and thus be pumped to the surface.

328. Wind Mill Pumps. Whenever water is pumped by means of hand pumps, the supply in the house is greatly limited. Sometimes the energy of the wind is utilized to run a wind mill pump, by which water is forced to a tank considerably higher than the highest faucet of a house (Fig. 323). This furnishes a supply that can be piped to the house. In this case the pressure of the water at a high level furnishes continuous water at the outlets.

FIG. 323.—WIND MILL PUMP

329. Compression Tank Water Supply. The wind mill pump and tank are today being largely supplanted by a force pump that is driven by a gasoline engine or an electric motor. By means of this pump, water is forced into a compression tank in the cellar of country houses. This system is superior to the other one in that it is not dependent upon the wind, and the tank, being in the cellar, is not subjected to the heat of the sun.

In such a system, water is forced into the bottom of a large cylindrical tank (Fig. 324). As the water level rises inside, the air is compressed, thereby exerting an increasing pressure downwards upon the surface of the water. When a faucet in the house above is opened, the water is forced through the outlet into the

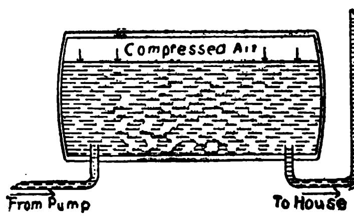


FIG. 324.—COMPRESSION TANK WATER SUPPLY

supply pipe, which supplies water to the various fixtures and tanks of the house, just as does the supply pipe from the street mains in city houses. As water is drawn off the pressure decreases, and this must be watched and the engine set running, in order to pump a fresh supply as needed. For this kind of pump four-cycle gasoline engines are generally used.

330. **Gasoline Engine.** Most of us are familiar with the gasoline engine as a motive power in automobiles and motor boats. Some are also familiar with its use in the country nowadays, to replace the windmill as a means of driving water pumps, circular saws, and other farm machinery.

This form of engine is run by the energy of combustion of gasoline vapor, which, when mixed with air in the right proportion, explodes with great violence. This explosion occurs in an inclosed cylinder in which there is a piston connected with a shaft, and is brought about by an electric spark which forms at a time when the mixture of gasoline vapor and air is under compression. The piston is forced to the other end of the cylinder and the shaft rotates as a result.

There are two types of gasoline engines, called the *two-cycle* and the *four-cycle*. The difference in them is in the frequency with which the explosion takes place. Calling the stroke of the piston from one end of the cylinder to the other end a *cycle,* in the two-cycle type, an explosion takes place every revolution of the shaft, or two cycles. In the four-cycle type (Fig. 325) the explosion occurs every two revolutions, or four cycles. The two-cycle engine is used almost exclusively on motor boats. The four-cycle engine has more extended use for other purposes.

331. **Four-Cycle Engine.** In this form, when the piston is made to move down by the crank, an explosive mixture enters

the chamber above the piston through the valve at the right. On the return stroke this mixture is compressed, and when the piston is at the top of its stroke, explosion is brought about by an electric spark. The force of the expanding gases drives the piston down, and the inertia of the heavy fly wheel fastened on the shaft causes the piston not only to move back and thereby force out the waste gases through the valve at the left, but to continue through another intake stroke and compression stroke. Thus one explosion brings about four strokes of the piston. The valves open inwards and are operated by cams which are connected with the shaft of the engine.

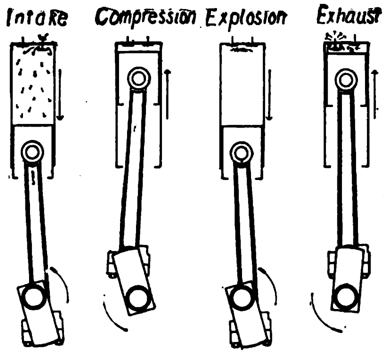


FIG. 325.—ACTION IN A FOUR-CYCLE GASOLINE ENGINE

On automobiles, several four-cycle engines are connected on one shaft, and so adjusted that the explosions take place in succession. If there are two cylinders, explosions occur every revolution of the shaft; with four cylinders, every half revolution. With six cylinders, there are three explosions to a revolution.

332. **City Water Supply.** In planning for a city water supply, large bodies of water are sought, as ordinary wells would not furnish water in sufficient quantity. If possible the source should be high above the city, so that if pipes are run from it the pressure will be sufficient to force the water out of faucets on the top floor of houses. Often such high lakes are not available; in such a case, where water from a lower source

must be used, a pumping station is necessary. Pumps force the water into reservoirs on some high land. From these reservoirs the water passes into the city mains, from which it enters houses through branch pipes.

Where an extra pressure is desired to drive the water into houses on hills, the pumps drive water directly into the mains. In order to keep this pressure steady and to prevent too great a pressure in the pipes at times when little water is being used,

FIG. 326.—WATER SUPPLY STANDPIPES

standpipes are erected at different elevated places (Fig. 326). Into these the extra water passes, to be drawn off at times when the demand exceeds the amount that is being pumped through the mains. In this way the pumps can be run at a more uniform rate during the times of both small and large consumption of water. The pressure of the water in the pipes will of course be determined by the height of the water in the standpipes, in all of which the level will be the same.

QUESTIONS

1. Explain why it is much farther down to the water in some wells than in others.

2. In what condition, as compared with atmospheric pressure, must the air in a compression tank be, in order that water may flow from a faucet 34 feet higher than the tank?

3. Explain why there are both a high and a low pressure water service in some cities.

4. What would you do if a cold water pipe in your house should burst?

DISTRIBUTION OF WATER IN A HOUSE

333. Where there is not a continuous water supply from a tank in a country house, the question of distribution need not be considered, as the water in this case is obtained as needed either by a bucket or by a pump.

Where there is a continuous water supply piped to a house, it is divided into a *cold water* and a *hot water* system.

334. **Cold Water Supply.** The cold water supply is led by branch pipes from the main supply pipe to the various cold water outlets and to the closet tanks. In cases where the cold water pipes are of the same size throughout the house, the turning on of one faucet is likely to diminish the flow through other faucets. To prevent this the main supply pipe should be larger than the branches.

335. **Hot Water Supply.** The hot water supply is provided by heating cold water in a kitchen range or in a gas water-heater. The cold water may come to these either *directly* from the cold water main, or *indirectly* through a supply tank, located high up in the house.

336. **Indirect Hot Water Supply System.** The tank in an indirect system is supplied with water from the cold water main through a valve called a *ball cock,* operated by a *ball float*

(Fig. 327). As the float rises with the rising water level, the supply of water is gradually shut off (see also Fig. 330). If the water level falls, the float drops with it, and the valve opens, allowing more cold water to enter the tank. From the bottom of the tank a pipe passes to the kitchen boiler, through the top of which it extends nearly to the bottom inside (see Fig. 37). From the tank there is also an *overflow pipe* to carry off the excess of water in case the valve does not properly cut off the supply when the tank becomes full. The other end of this overflow pipe should be over a closet tank or a sink, such as that in the kitchen.

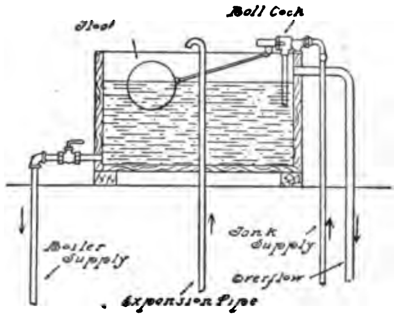


FIG. 327.—HOUSE SUPPLY TANK, INDIRECT SYSTEM

337. Coal Range Water Heater. Where the water is heated by a coal range, a pipe passes from the bottom of the boiler to the lower part of the water back in the range (see Fig. 37). The upper part of the water back is connected to the side of the boiler about a third way up. Convection currents form as indicated, and the hot water collects in the top part of the boiler. From here it is forced out through the hot water supply pipes when any hot water faucet is opened.

338. Gas Water Heater. In case a gas heater is used for heating the water, the bottom of the boiler is connected to the lower end of the heater coil, while the pipe from the top of the coil is connected to the hot water outlet pipe at the top of the boiler (Fig. 328). The reason for the difference in the manner of connecting this last pipe is that when the gas heater is used,

hot water is wanted at once, and will be drawn off long before the water in the boiler is heated to its boiling point. In the case of the coal range, the water may be heated to boiling, since it is not drawn off at once. If the return pipe from the stove were connected with the boiler at the top, steam would collect in the upper part, while the water at the bottom might be considerably below the boiling point. If the steam is made to enter the boiler half way up and there to mix with the water, the lower temperature of this water will condense the steam and the heat will be distributed more evenly.

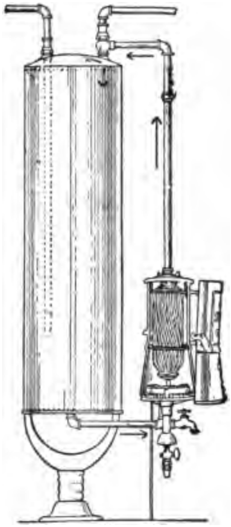


FIG. 328.—GAS WATER HEATER CONNECTIONS

Sometimes an "expansion" pipe passes from the top of the boiler to the tank upstairs. The purpose of this is not so much to allow for expansion as to furnish an outlet for the air that is set free from solution in the cold water when the latter is heated. The *cold water pipe* from the tank allows for *expansion* in the boiler.

Note.—The term "boiler" is incorrectly applied to the tank in the kitchen. The water is *really* heated in the water back or in the coils of the gas heater. The "boiler" is only a *storage tank,* by means of which large amounts of water may be heated at one time.

339. **Circulation Pipe.** Many persons are bothered by having to draw off considerable cold water from the hot water faucet before hot water comes out. This is because the boiler is some distance away, and the hot water, standing for some time in the connecting pipe, has cooled. To prevent this waste

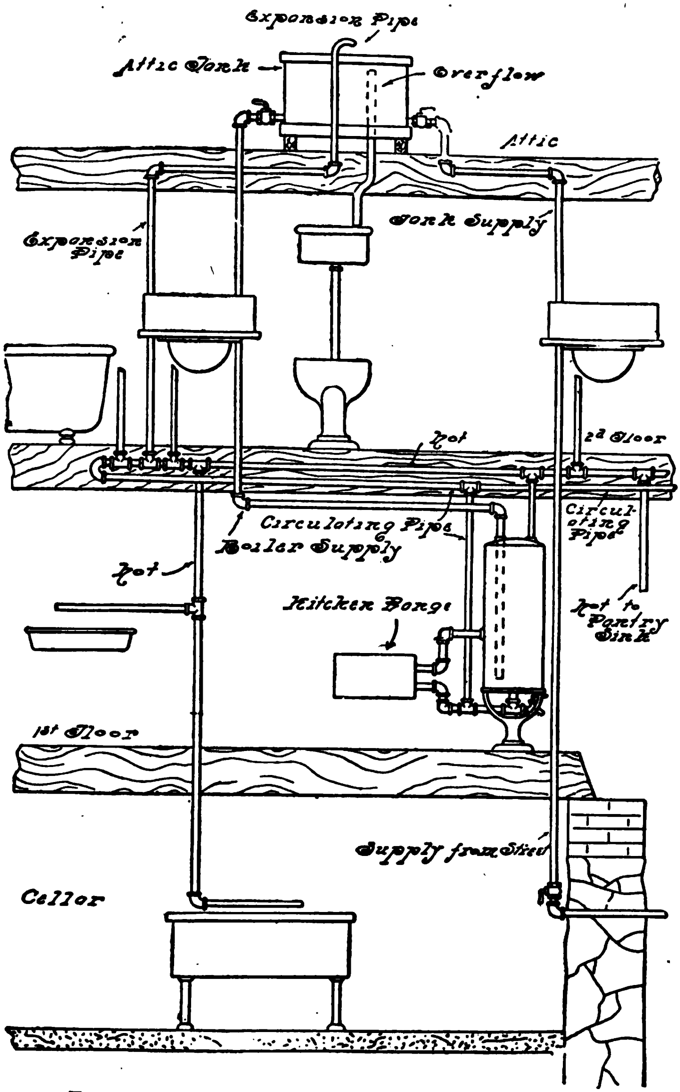


FIG. 329.—HOT WATER SUPPLY AND DISTRIBUTION

and delay in getting hot water, a *circulation pipe* is sometimes placed in the hot water system (Fig. 329). This pipe connects the lower part of the boiler with the hot water supply pipe at a point beyond the last branch. By means of this the water, as it cools, is kept circulating in the supply pipe. In this way, when we desire hot water, it is necessary to draw from a faucet only the water that stands in the branch pipe which leads from the main hot water pipe to the faucet.

340. **Direct Hot Water Supply.** In this system the cold water supply comes to the boiler directly from the main pipe instead of from a tank. The pressure of such a supply, if it is from the city mains, is considerably greater than that from a tank in the top of the house. Consequently there must be a much stronger boiler to withstand this extra pressure. The expansion of the water must either bring about a pressure backwards upon the water in the main, or be cared for by means of a check valve. The distribution of the hot water is the same as in an indirect supply system.

341. **Freezing of Water Pipes.** Many fatal explosions of water backs in stoves have occurred when people have started fires in the stoves after very cold nights. During the night the water in the pipes that connect the water back with the boiler has frozen, so that there is no chance for expansion of water in the water back when the fire is started. The result is generally the bursting of the water back. Too great precaution cannot be taken in the matter of starting fires in heaters where there is any possibility of frozen water pipes.

342. **Closet Tank.** The closet tank serves the purpose of supplying a large volume of water in a short interval of time for flushing water-closets, in order to remove waste matter thoroughly and rapidly. This tank is similar to the house tank, but

is smaller. The inlet is regulated by a ball cock and float, while at the outlet there is a stopper which is lifted when the chain that is attached to a lever is pulled.[1]

Tanks as used to supply water to water-closets are of two classes: those from which water flows only as long as the chain is pulled, and those which become nearly empty when once the chain is pulled, whether or not it is soon released.

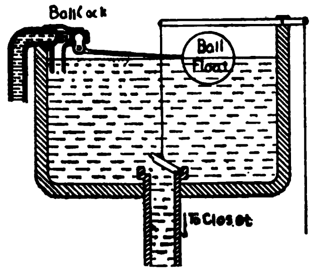


FIG. 330.—OLD FORM OF CLOSET TANK

To the first class belong the old-fashioned tanks, the stopper in which is hinged and remains up only when held up (Fig. 330). When released, it is forced into its seat by the pressure of the water above.

To the second class belong the many types of modern tanks. They differ mainly in the manner in which the tank is emptied, when once the stopper is lifted from its seat. One of the simplest of these is that represented in section by Figure 331*a*.[2] In this the outlet valve consists of a soft hollow rubber ball *r*, which fits snugly into the cup-shaped opening *s*. As long as this ball is in place, the pressure of the water above holds it down firmly and no water gets by. If, however, the ball is lifted by the chain pull, the added water pressure upwards underneath is sufficient to keep it buoyed up as long as it is covered with water. The water flows out through the outlet *f* until the level drops about half way down the sides of the rubber ball. The ball then drops back into place by its own weight, which now

[1] In some tanks, that are slightly above and behind the closet, the chain pull is replaced by a knob that is pressed to set the tank in operation.

[2] The float and inlet valve in these tanks are not shown in the Figures 331*a* and 331*b*, as they are the same in principle as in Figure 330.

produces a greater downward pressure than that of the water upwards underneath it.

In another form of tank, siphonic action is the working principle. This is started by the lifting of the valve *v* (Fig. 331*b*). In this tank the water level in the tube *a* is the same as that in the tank, when it is not in action. When the valve *v* is raised, water flows through the opening into the flush pipe *f*.

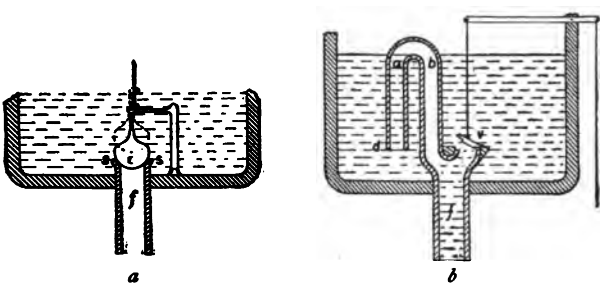


FIG. 331.—MODERN CLOSET TANKS

When *v* is closed, on the release of the chain pull, this water in the flush pipe acts as a piston pulling downwards, and makes the water in *a* rise above the bend between *a* and *b* and overflow into *b*. Siphonic action starts and water flows through *a* and *b* until the tank level reaches *d*, the lower end of *a*. The siphon flow is broken by the air which now enters *a*, and the tank refills to the level shown.

343. Fixtures. Fixtures include such appliances as faucets, tubs, bowls, sinks, water-closets. Faucets serve to regulate the supply of water from the pipes. Sinks, bowls, and tubs serve as receptacles for water for bathing and washing purposes. Water-closets serve to remove waste matter from the house.

344. Faucets. Faucets, as used to regulate the quantity of water that passes out of the pipes, are of several types, of

which the *screw*, the *compression*, and the *spring* forms are commonest.

In the screw type (Fig. 332), when the handle is screwed

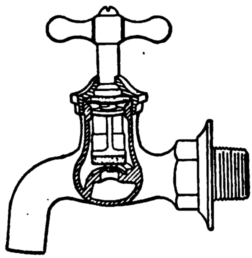


FIG. 332.—SCREW TYPE OF FAUCET

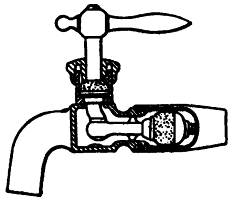


FIG. 333.—COMPRESSION TYPE OF FAUCET

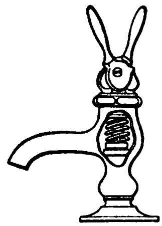


FIG. 334.—SPRING TYPE OF FAUCET

down a washer is forced over the opening, thereby forming a secure seal.

In the compression type (Fig. 333), a half turn of the handle forces a rubber knob into the opening.

In the spring type (Fig. 334), the pressure of a spring holds the washer against the opening. When the handles are squeezed together, the washer is lifted from its seat and the water passes through the opening and out of the faucet.

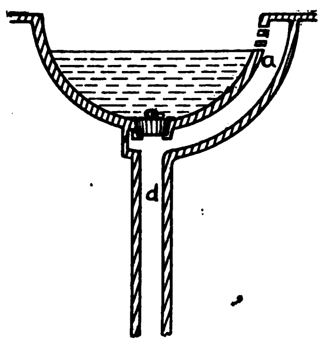


FIG. 335.—BOWL WITH OVERFLOW PIPE

345. Sinks, Bowls, and Tubs. These are of many shapes and sizes. Bowls and tubs are supplied with an overflow pipe *a* which connects with the drain pipe *d* just below the outlet (Fig. 335).

Questions

1. What would you do if a hot water pipe leaked?
2. What would you do if the kitchen boiler leaked?
3. What disadvantage can you find in a circulation pipe?
4. State an objection to placing water pipes on the outside walls of a house.
5. Explain why water often comes out of the tank overflow pipe when a fire is started in a kitchen range.
6. Explain how a closet tank may serve as a means of preventing back pressure on the cold water mains in a direct hot water supply system.
7. Explain how to proceed in putting a new washer on (1) a cold water faucet and (2) a hot water faucet.
8. Why are faucets of the compression type used mostly on bathtubs?

WASTE REMOVAL

346. Sewerage System in a House. While a pure water supply is very essential to health, the proper removal of waste, both liquid and solid, is of vital importance.

The removal of garbage does not concern the plumbing system of a house. The removal of sewage in the form of dirty water that has been used for bathing or cleansing purposes, as well as of human excreta, takes place through the *sewerage system* of a house. This starts at the sinks, bowls, tubs, and closets, and ends at the cesspool or city sewer. It consists of a system of pipes called the *plumbing stack*. There is one large pipe (Fig. 336) which passes nearly vertically through the house. This is called the *soil pipe*, which, through branches

called *waste pipes*, is connected with the fixtures. When water enters any of these waste pipes, all of which slant somewhat toward the soil pipe, it flows down to this pipe, through which it passes to the *house drain* and thus out of the house.

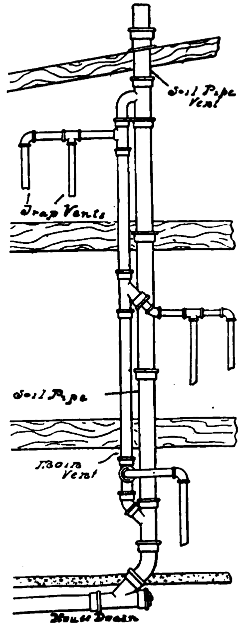


FIG. 336.—PLUMBING STACK

Such an arrangement seems simple enough, the force of gravity acting to make everything flow to the lowest point, the sewer. Unfortunately, sewer gas from decomposing substances in the sewer may rise through the soil pipe, and, unless in some way checked, can pass through the branch pipes into the house, thus contaminating the air supply. To prevent such an occurrence, *traps* are placed in the waste pipes below the fixtures.

347. Traps. Traps are water seals. In their construction (Fig. 337) advantage is taken of the fact that a gas will not force its way into water to a lower point, unless its pressure is greater than that upon the water surface at the other side of the bend. Just as long as the pressure of the air in the soil pipe is the same as that of the air on the fixture side of the trap, no movement caused by air pressure on the two arms *a* and *b* will occur. If,

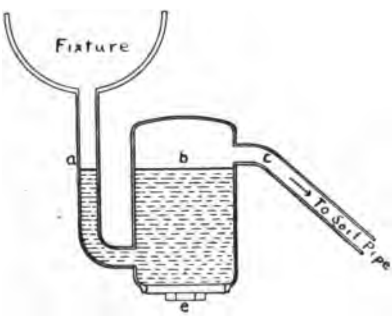


FIG. 337.—TRAP

however, the water level on the side *a* rises through water coming down from the fixture above, the level on the side *b* will rise also, until it reaches the opening into *c*, through which water will flow into the soil pipe. This action will go on just as long as the level in *a* is higher than the opening into *c*. When the water ceases to come from the fixture above, the level in both arms will drop to a little below the level of the opening. The water below the line of *c* is called the *water seal.*

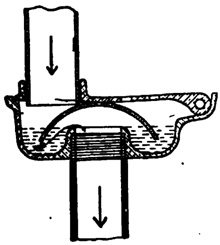


FIG. 338.—REFRIGERATOR TRAP

348. Refrigerator Trap. A water seal is utilized in the refrigerator trap (Fig. 338), by which water from the melted ice may pass down and out from the ice chamber, overflowing into the drip pan as the level rises inside the tube. No warm air can get back into the refrigerator because of this water seal.

349. Types of Traps. The trap described in Section 346 is called the *drum* trap. It is made in many forms, in one of which a slight upward curve of the inlet pipe makes the water swirl around inside the trap, forcing out any solid matter that would otherwise settle to the bottom and clog the trap.

Of late years another type of trap known as the *S* trap has come into extensive use. In this (Fig. 339) the large chamber of the drum trap is replaced by a continuation of the pipe that passes downward from the fixture. With the introduction of this form of trap, which is very easily made and quite economical, a trouble known as *siphonage* is encountered.

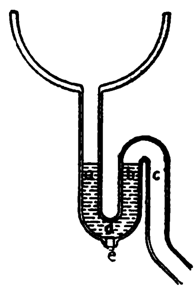


FIG. 339.—S TRAP

350. Siphonage of Traps. Let Figure 339 represent a sectional view of a trap of the S type, with the water seal *a b*. Suppose a large volume of water enters the side *a* from the fixture. The level in *b* rises and the water flows over into *c*, where it forms a piston and siphonic action starts. As a result, when the flow of water from above *a* ceases, the level in *a* drops down below *d* until air can pass up the side *b* and thus break the siphon flow. In this manner nearly all the water in *a* and *b* is removed, so that there is not enough to seal the lower bend completely. Since *c* is connected with the soil pipe, it is easy to see that if there is any sewer gas in the pipe, it can readily pass up into the house through the fixture.

351. Venting of Traps. In order to diminish the possibility of the loss of water seals in traps through siphonage, a system of *venting* has been introduced. An opening made in the top of the bend between *b* and *c* (Fig. 340) prevents siphonic action, since the atmosphere is then continually acting on the water there, and thus breaks the continuous stream between *b* and *c*. The water level of *a* can drop only slightly below the bend between *b* and *c* when the supply from above stops. The inertia of the moving column alone makes it fall below this level.

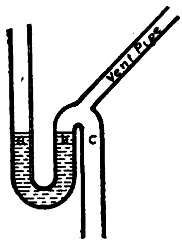


FIG. 340
VENTING

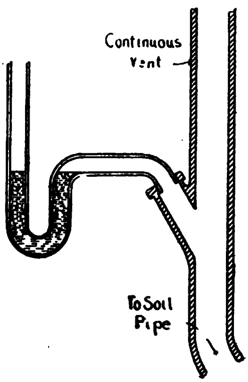


FIG. 341.—CONTINUOUS VENTING

The latest plumbing regulations in some localities require that vents for traps shall be continuous. In such a system of venting (Fig. 341) the waste

pipe from the trap passes horizontally into the wall of a house and passes down to the soil pipe through a continuation of the vent pipe. Such a form of trap is called the half S trap.

In the modern system of venting traps, another vertical pipe known as the *main vent pipe* is added to the stack (Fig. 336). This pipe starts at the lowest fixture and passes to the roof of the house.[1] To it pass the vent pipes from all the traps. Through this main vent pipe air at atmospheric pressure acts upon the top of each trap, thus preventing the possibility of siphonage.

352. **Non-Siphon Unvented Trap.** Many traps in which siphonic action cannot take place have been invented. The time is undoubtedly coming when such a trap will be generally introduced, and the large expense of venting in houses will be eliminated; for in spite of the law to the effect that traps must be vented, there is a possibility that the water seal will be broken through causes other than siphonage. Commonest of these is *evaporation*. The water in both arms of the water seal of a vented trap is exposed to the atmosphere, on one side *a* directly through the fixture, and on the other side *b* indirectly through the vent pipe. If the fixture is left unused for any great length of time, the water will evaporate to such an extent that there will be a free passage for gas through the trap. This will not happen so readily in a *non-siphon* unvented trap, as in this there is a chance for evaporation on only one side of the water seal. Figure 342 represents in section one of the good non-siphoning traps.

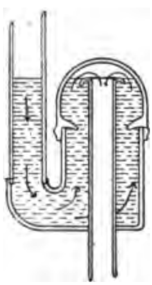


FIG. 342.—NON-SIPHON TRAP

353. **Grease Trap.** From the kitchen sink, large quantities

[1] Sometimes the soil pipe passes through the roof, and the main vent pipe is connected to it just below the roof.

of unnecessarily greasy waste are often allowed to pass into the trap and waste pipe. This results in a large loss. As long as the water is warm, the grease is in a more or less liquid state. As it cools in the trap, however, it solidifies and collects on the walls, thus interfering with the proper working of the trap. The vent pipe may even become clogged with grease to such an extent that there is nothing to prevent siphonage.

In ordinary drum or S traps, there is a cap that may be unscrewed, either to remove any obstruction or to clean out the vent pipe that has been stopped up with grease. In the best forms of traps these caps are on the bottom or on the sides below the water surface. (See *c*, Figs. 337 and 339.)

To prevent an accumulation of grease in the vent pipe, ***grease traps*** are frequently placed under kitchen sinks, particularly in restaurants and hotel kitchens. Figure 343 represents the section of one form of such a grease trap. The trap fits into the sink, the top of it being level with the bottom of the sink. The greasy water enters the trap through the holes *h h h*, and rises in *a* and *b* to the level of the outlet pipe as indicated. Cold water passes around the central part *a b*, thus cooling the waste water, and causing the grease to solidify. The grease, being less dense than water, floats upon the upper part in *b*. To remove the grease, the central part *a b* is lifted out. When this is done the cylinder *d*

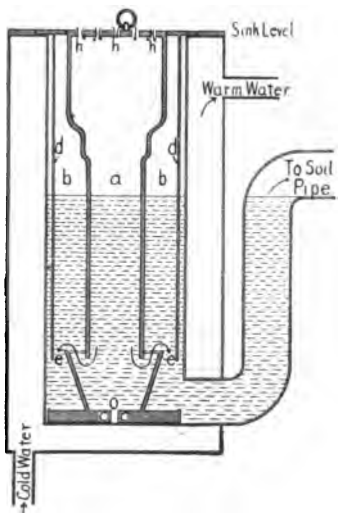


FIG. 343.—GREASE TRAP

fits into a groove around the base *c* and is lifted by *c*. Thus no grease can get out, though the water in *a* and *b* can pass through the hole *o*. The cylinder *d* can then be slipped off upwards and the grease can be scraped from the outer surface of *a*. Soap can be made from this grease.

354. Water-Closets. Water-closets are of various forms. In all of them there is a water seal, the closet itself forming a trap. Of the forms of closets in use today, we have, in the order in which they have been adopted, the *short hopper, wash out, wash down, siphon,* and *siphon jet closets.*

355. Short Hopper Closet. This is the oldest type of closet permitted by law in communities where there are regulations concerning plumbing fixtures. The water seal (Fig. 344) connects the *hopper* or *bowl* with the waste pipe *a*. The trap is vented through *b*. The waste pipe *a* leads to the soil pipe. When the closet is flushed, water enters at the top, and passes around the rim, through which it flows down the sides of the hopper. The disadvantage of this type is that the hopper is dry when not in use, and it may become foul smelling, as the water at flushing may not clean it thoroughly. Such a type of closet is used mostly because of its cheapness. It is inclosed in woodwork.

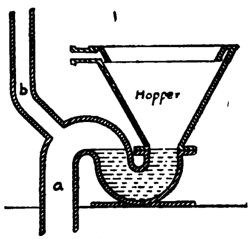


FIG. 344.—SHORT HOPPER CLOSET

356. Wash Out Closet. In this form of closet (Fig. 345) there is added a shelf *s* in which there is water when the closet is not in use. The trap is of the same form as in the short hopper closet, but instead of being separate from the closet proper, it is a part of it, so that the whole closet is of one piece.

357. Wash Down Closet. In this type, the inner arm of

the trap has a larger water surface, so that there is less of the bowl exposed for accumulations (Fig. 346).

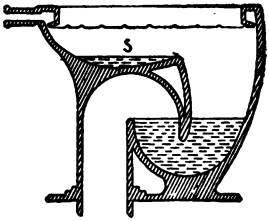


FIG. 345.—WASH OUT CLOSET

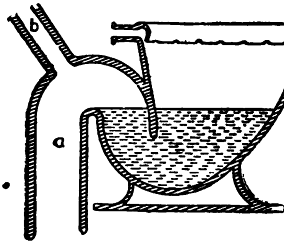


FIG. 346.—WASH DOWN CLOSET

358. Siphon Closet. The difference between the wash down and siphon types (Fig. 347) is in the outlet arm of the trap. While in the wash down type it leads directly to the soil pipe, in the siphon type it turns nearly at right angles, and is constricted at one place *a*. In this way water collects and acts as

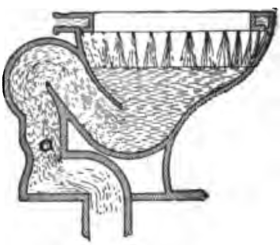


FIG. 347.—SIPHON CLOSET

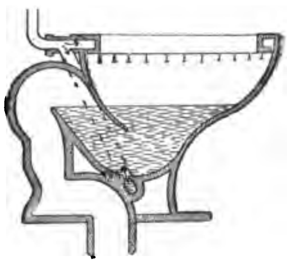


FIG. 348.—SIPHON JET CLOSET

a piston in the arm, so that the contents of the bowl of the closet are swept out because of a violent siphonic action. This action is much less pronounced in any one of the three preceding types.

359. Siphon Jet Closet. In this type of closet (Fig. 348) we find the best and most up-to-date form. In it the siphonic

action is hastened by a jet of water which enters the bottom of the bowl. This water comes from the tank supply, which divides at the point where it enters the closet, a part to run around the rim of the bowl, the other part to flow through a *passage* at the side and enter the bowl at the bottom.

The figures representing the different types are merely one of many different forms of each type. The principle upon which all those of one type act is, however, the same.

360. House Drain Trap. As an added precaution against sewer gas, a trap is placed in the house drain, just before it leaves the house. This is known as the ***house drain trap***. It is of the *running trap* type (Fig. 349), one of the simplest forms, and merely furnishes a water seal. A rise in the water level on the soil pipe side of this trap causes an overflow into the house sewer pipe on the other side.

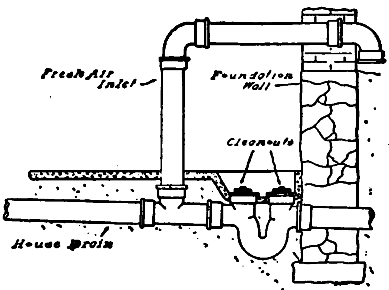


FIG. 349.—HOUSE DRAIN TRAP AND FRESH AIR INLET

361. Fresh Air Inlet. Near the main house drain trap, on the soil pipe side of it, there is a vent pipe known as the *fresh air inlet*. This is to insure a free circulation of air through the soil pipe and the main vent pipe, as well as to prevent any extra pressure in the soil pipe from breaking the seal of the main trap.

Final Review Questions

1. If, in taking a picture, the photographer wishes a full length view, must the person be nearer to or farther from the camera than when a picture of the head only is being taken?

2. Explain why firemen wear flannel shirts both in winter and in summer.

3. Explain the intense heat produced by the "burning glass."

4. Why does a farmer prefer a winter with abundant snowfall?

5. Explain the difference between men's and women's voices.

6. Explain how the water in an aquarium may be removed without disturbing the fish, at times when the water is being replenished.

7. Why do instantaneous water heaters sometimes burn out if they are left out of water with the current turned on?

8. Why is the thunder clap generally not heard for some instants after the lightning flash is seen?

9. What is the objection to wearing rubbers in a house?

10. Why does a strong side wind interfere with the direction in which a golf ball or a tennis ball moves?

11. What is the object of putting a glaze on china?

12. Explain how a fish, which has an air bladder in it, can rise and fall in water?

13. Why are piano wires struck one-seventh from the end?

14. How does the low specific heat of mercury make it useful in thermometers?

15. Explain why the sun does not warm the United States so much in winter as in summer.

16. Why are furnace pipes shiny?

17. Explain the wavering condition of objects as seen through the air above a hot stove, or above the sand or sidewalks on a hot day in summer.

18. Can a room in a cellar be heated by a hot water radiator? Explain.

19. Explain the whistling of the wind when it blows violently.

20. Why does the nose look large in proportion to the rest of the face when we stand near a convex mirror?

21. Why is earth packed tightly around a plant when it is first set out?

22. The fact that solid fat floats on melted fat indicates what two things?

23. Explain the murmur of telegraph wires.

24. Why can an owl not see well in the daytime, but exceedingly well at night?

25. How is it possible to tell which of two bars is a magnet, without the use of iron filings, a compass, or a means of suspension?

26. Why are the steam pipes of a boiler kept polished?

27. The picture, as ordinarily taken with a camera, is smaller than the object. Can you suggest a way in which the picture may be made larger than the object?

28. Explain the saying that "sunlight puts out a fire."

29. Why does a radiator just underneath a window warm a room more effectively than if it were on the opposite side of the room?

30. Explain the cracking of the glaze on cheap pottery when it is heated in an oven.

31. Explain how the flooding of cranberry bogs protects them against frost.

32. Explain the action of the dampers in a coal stove.

33. Why would it not be practicable to have a furnace placed upstairs in a house?

34. Explain why molasses candy "whitens" when it is pulled.

35. Why is the sun's light dimmer towards sunset?

36. Why do our eyes tire if we read for a long time, and do not tire if we look off at a distance for a long time?

37. What makes the size of the pupil of the eye change?

38. Why does oil float on water, while alcohol does not? Both are less dense than water.

39. Why is it more difficult to skate than to walk?

40. Why are ground glass or opalescent globes used on gas and electric lights?

41. Why will not old dry popcorn "pop" so well as new?

42. Which are warmer in sunlight, white or black furs?

43. Why does a tight-rope walker carry a parasol or a long pole?

44. Why is iron better than brick or porcelain for the tops of stoves?

45. Why is it not proper for the cold water inlet to end at the top of the kitchen boiler?

46. Explain why fruits and vegetables bottled in round glass jars look larger than they really are.

47. Why does standing upon a rubber mat insure one against being struck by lightning?

48. What evidence have we that the pitch of a note has nothing to do with the speed with which sound waves move through the air?

49. Why should preserve jars be heated before hot preserves are poured into them?

50. Why does the top of a cake of ice in a refrigerator melt faster than the bottom part?

51. Explain the play of color in chandelier pendants.

52. Why are leather washers used in faucets?

53. Why is it so difficult to untie a wet knot?

54. Why do knots stay tied?

55. Why do people sometimes wear shades over the eyes?

56. Why are sounds heard better across water?

57. Why must the main electric wires in a house be larger than the branch wires?

58. Why do some old persons need two pairs of glasses?

59. What is the object of a trap in a refrigerator?

60. How are fireproof safes made?

61. In what way do the color and the texture of clothing enter into how warm they feel?

62. Compare an ice box, which has one compartment only, with a refrigerator, as far as cooling effect is concerned.

63. Why can sunlight warm a room without either melting the frost on the window through which it passes, or warming the air outside?

64. Explain the action of a blotter.

65. Explain the change in pitch that a violin string undergoes in damp weather.

66. Which is better for the back of a fireplace, bricks or polished metal? Explain.

67. Why does dust leave a rug or duster when it is shaken?

68. If the door between a warm and a cold room is opened, what will be the course of the air currents between the rooms?

69. Why should colored ribbons or cloth be matched only in daylight?

70. How do the locust and the cricket produce their characteristic notes?

71. Explain why a hot lamp chimney cracks when a drop of water falls upon it.

72. Explain the mists that frequently appear over marshes, brooks, or snow after a warm day.

73. Why is it difficult at night to see out of a room in which a lamp is lighted?

74. In a projection lantern should we use a lens of longer or shorter focus in a small room than in a large hall?

75. Why should very nearsighted persons wear glasses when reading, even though they can, unaided, read without effort?

76. Explain how the bottom of a broken bottle may set fire to dry leaves, when sunlight falls upon it.

77. Why are telephone wires strung on glass supports?

78. Why is the pitch of a piano slightly higher in a cold room than in a hot room?

79. Why is it impossible to stand sidewise to the wall, on one foot, when that foot touches the wall?

80. To what type of lever does the key of a piano belong?

81. Explain the "soughing" of the pines.

82. Why can a person move a heavy piece of furniture most easily by pushing low down?

83. Why does the ball float in a tank rise with the water?

84. Why is it difficult to pour water from a straight jar without a lip?

85. Explain why "rolypolys" right themselves.

86. Molasses candy breaks when struck, but will bend in the fingers. Explain.

87. Explain how liquid gets into a medicine dropper.

88. Explain why dish handles sometimes break off if the dish is lifted too suddenly by them.

89. Why do people wear white clothes in summer?

90. Why are hot water boilers smooth on the outside?

91. Why is sawdust packing used in ice houses?

92. Why do people wear rubbers? Explain why they serve this purpose.

93. What is the advantage of using vitrified or glazed brick on houses?

94. What temperature change takes place in the body when more heat is generated than is radiated?

95. Why is a thermos bottle silvered?

96. Why does lowering the handles make it easier to push a wheelbarrow over bumps?

97. Carbon dioxide gas is denser than air. Explain why the impure air is mostly at the top of an ordinary room.

98. Why do tall chimneys have better drafts than low ones?

99. Explain the action of the check draft in a stove front.

100. Why is a drowning person more likely to sink if he throws up his arms?

101. Explain why a stove heats a room better than does an open fireplace.

102. Where must an object be placed in order to get a real image with a convex lens?

103. What is the object of using a double boiler in cooking?

104. To what classes of machines do the pincers and the razor belong?

105. Explain why a finger is more likely to be crushed when

caught between the door and the jamb on the side where the hinges are than on the side where the latch is.

106. A piece of ice is placed in a tumbler, and water is poured in to fill the tumbler to the brim. The ice floats on the water, with part of it above the surface. As the ice melts, will the water overflow? Explain.

107. Why are radiators built in so many sections, and the surfaces made so rough?

108. Describe and explain how violets can be raised out of doors under glass in wintertime.

109. Why is iron used in preference to brass or some other metal for ironing clothing?

110. State two ways in which a room may be thoroughly ventilated, and state which of the two ways is better and why.

111. How may tents be waterproofed?

112. Why can a person hear better by placing the ear at the small end of a megaphone?

113. Does dew fall? Explain.

114. Explain why it is difficult to brush lint from clothing on cold dry days.

115. Why must the lower end of a long ladder be braced against something, while the ladder is being raised?

116. Explain why it is difficult to balance a long stick on its end.

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